THE DEVELOPMENT OF A HYBRID KNOWLEDGE-BASED SYSTEM FOR INTEGRATED MAINTENANCE STRATEGY AND OPERATIONS IN AN AUTOMOTIVE INDUSTRY ENVIRONMENT

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The Development of a Hybrid Knowledge-Based System for Integrated Maintenance Strategy and Operations in an Automotive Industry Environment

The Development of a Hybrid Knowledge-Based (KB) System/ Gauging Absences of Pre-Requisites (GAP)/Analytic Hierarchy Process (AHP) Methodology for Integrated Maintenance Strategy and Operations in an Automotive Industry Environment

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ABSTRACT

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Thesis Title: The Development of a Hybrid Knowledge-Based System for Integrated Maintenance Strategy and Operations in an Automotive Industry Environment

Sub-Title: The Development of a Hybrid Knowledge-Based (KB) System/ Gauging Absences of Pre-Requisites (GAP)/Analytic Hierarchy Process (AHP) Methodology for Integrated Maintenance Strategy and Operations in an Automotive Industry Environment

Keywords: Integrated Maintenance Strategy and Operations, Business, Manufacturing, Automotive Industry, Knowledge Management, Knowledge-Based (KB) Expert System, Gauging Absences of Pre-requisites (GAP), Analytic Hierarchy Process (AHP)

The dependency of maintenance as a manufacturing logistic function has made the considerations of maintenance decisions complex in nature. The importance of maintenance has escalated significantly by the increasing of automation in manufacturing processes. This condition switches the traditional maintenance perspective of “fire-fighter” into the business competitive driver. As a consequence, maintenance needs to consider other related aspects of decision making to achieve competitive advantage.

This research aims to develop a hybrid Knowledge-Based (KB) System/GAP/AHP methodology to support the integration of maintenance decision with business and manufacturing perspectives. It constructs over 2000 KB rules on Strategic Stage (business and manufacturing aspects) and Maintenance Operations Stage (maintenance aspects). Each aspect contains KB rules attached with GAP analysis to assess the gap between current and prerequisite condition. AHP analysis is then deployed to compare those aspects structurally in a pair-wise manner to identify the critical ones to be rectified. This hybrid KB system is useful in reviewing the existing maintenance system performance and provides reasonable recommendations to improve maintenance performance with respect to business and manufacturing perspectives. Eventually, it indicates the roadmap from the current state to the benchmark goals for the maintenance system.

This novel methodology of KBS/GAP/AHP to support maintenance decision is developed for a particular application in the automotive environment. The validation is conducted in two automotive companies in Indonesia and one published case study in an automotive company. The result confirms that the developed KB system can provide the valid, reasonable and consistent result to propose structured recommendation for maintenance improvement priority.

Supervisors: Dr J. Eduardo Munive-Hernandez, and Prof M. Khurshid Khan

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LIST OF ABBREVIATIONS AND NOMENCLATURES

AgM	Aggressive Maintenance
AHP	Analytic Hierarchy Process
AI	Artificial Intelligence
AM	Application Manager
AMT	Advanced Manufacturing Technology
ANN	Artificial Neural Network
BCM	Business-Centred Maintenance
BP	Bad Point
BSC	Balanced Scorecard
CARs & FoF	CADCAM, Robotics and Factories of the Future
CBM	Condition-Based Maintenance
CBR	Case-Based Reasoning
CI	Consistency Index
CM	Corrective Maintenance
CMMS	Computerised Maintenance Management Systems
CR	Consistency Ratio
DCOV	Define-Characterise-Organise-Verify
DeA	Design Activity
DMAIC	Define-Measure-Analyse-Improve-Control
ES	Expert System
FMA	Failure Mode Avoidance
FMECA	Failure Mode Effects and Criticality Analysis
FMS	Flexible Manufacturing System
FS	Fuzzy System
FTA	Failure Tree Analysis
GA	Genetic Algorithm
GAP	Gauging Absences of Prerequisites
GP	Good Point
HSSE	Health, Safety, Security and Environment
ICAM^{2}E	International Conference on Advances in Mechanical and Manufacturing Engineering

ICT	Information and Communication Technology
IMSO	Integrated Maintenance Strategy and Operations
JIT	Just In Time
KB	Knowledge-Based
KBIMSO	Knowledge-Based System for Integrated Maintenance Strategy and Operations
KPI	Key Performance Indicator
ME	Manufacturing Equipment
MICT	Maintenance Information and Communication Technology
MID	Maintenance Information and Documentation
MMat	Maintenance Material
MoA	Modification Activity
MOrg	Maintenance Organisation
MP	Manufacturing Process
MPers	Maintenance Personnel
MPol	Maintenance Policy
MTBF	Mean Time Between Failure
MTools	Maintenance Tools
MTTF	Mean Time to Failure
MTTR	Mean Time to Repair
OEE	Overall Equipment Effectiveness
PC	Problem Category
PdM	Predictive Maintenance
PIC	Production and Inventory Control
PM	Preventive Maintenance
PQ	Process Quality
PV	Priority Vector
RBM	Run-Based Maintenance
RCA	Root Cause Analysis
RCM	Reliability-Centred Maintenance
RDC	Research and Development Centre
RepA	Repairing Activity
RetA	Retaining Activity
SVA	Shareholder Value Analysis
TBM	Time-Based Maintenance

TOPSIS	Technique for Order of Preference by Similarity to Ideal Solution
TPM	Total Productive Maintenance
TQM	Total Quality Management
YTD	Year to Date

LIST OF PUBLICATIONS

Journal Papers:

1. Milana, M., Khan, M. K. & Munive-Hernandez, J. E. (2017) Design and Development of Knowledge-Based System for Integrated Maintenance Strategy and Operations. Concurrent Engineering, **25** (2017), 5-18.

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2. Milana, M., Khan, M. K. and Munive, J. E. (2013) A Framework of Knowledge-Based System for Integrated Maintenance Strategy and Operation. In: *International Conference on Advances in Mechanical and Manufacturing Engineering (ICAM^{2}E)* Kuala Lumpur, Malaysia.

CHAPTER 1

Introduction

1.1 Background

The significant growth of technology has led to companies utilising more machines to improve their operational performance (Sánchez and Pérez, 2005). In the automotive industry, this shifting is also influenced by the competitive stress to provide high and consistent quality products at low cost and available on demand. As a consequence, the important issue is not only the way of adopting advanced technology into the system, but also ensuring that the high-technology equipment can work properly as it should do. According to these needs, maintenance is recognised to play a principal role so equipment can provide the desired service (Márquez, 2007).

Recently, maintenance works to achieve enterprise goals and it requires a significant investment of physical assets in performing the support functions (Tsang, 2002). In addition, Pinjala et al (2006) pointed out that the recent development of technology, concept and philosophies of production such as Advanced Manufacturing Technology (AMT), Just-In-Time (JIT), Total Productive Maintenance (TPM) and Outsourcing will significantly increase the nature of maintenance complexity and cost in the future. Mobley (2004) claimed that maintenance cost is the biggest portion of operating budgets in the majority of plants. It has been investigated that the spend on maintenance cost varies in different industries from around 15 to 40 percent of total production cost (Al-Najjar and Alsyouf, 2003). Meanwhile, 30 percent of total staffing, the largest, is allocated to the maintenance and production departments (Dekker, 1996 ; Garg and Deshmukh, 2006). Moreover, Haroun and Duffuaa (2009) claimed that 2 – 10% of the company revenue could be allocated for maintenance cost. Unfortunately, one-third of this cost was wasted as the impact of ineffective implementation of maintenance (Mobley, 2002). Unnecessary inspection and repair lead to increased costs. On the other hand, ineffective maintenance causes a late response to deterioration leading to catastrophic failure.

As a logistic function, maintenance is commonly integrated into a manufacturing process (Simões et al., 2011). Maintenance plays a role as facilitator to support manufacturing process working on its expected performance. It also contributes substantially to minimize equipment downtime, increasing productivity, improving quality and assuring equipment reliability (Duffuaa et al., 1999). In this state, maintenance adds value to the manufacturing process. Since manufacturing is the spearhead of business goal in producing the desired products, maintenance function becomes another important aspect contributing dominantly to the corporate goal.

Unfortunately, the dependency of maintenance to manufacturing has previously put this function into a marginal consideration. Many kinds of literature in the past have pointed to manufacturing as one of the drivers of competitive achievement (Avella et al., 2001; Vickery et al., 1993; Chang et al., 2003; Williams et al., 1995; Amoako-Gyampah and Acquaah, 2008; Sun and Hong, 2002), but not maintenance. Maintenance is not counted as a substantial function as long as the manufacturing works in the expected performance. Instead, when the manufacturing process is deteriorating, production target is not achieved, quality decreases, and the corrective action eats up the production budget, only then maintenance is realised as another important factor influencing the company performance. For these reasons, since the early 2000s maintenance has been noticed as an integral part of the business process Parida and Kumar (2006). The company requires proper strategy to work in supporting the manufacturing process.

In accordance with its direct correlation to manufacturing function, maintenance is also recognized to influence many other variables in an entire organisation. Sharma et al (2011) identified the linkage of maintenance with health, safety, security and environment (HSSE) objectives, maintenance cost and cost of lost production. Similarly, Parida and Chattopadhyay (2007) claimed that maintenance could influence financial report, customer satisfaction, employee performance, HSSE rating, and Overall Equipment Effectiveness (OEE). Furthermore, Kutucuoglu et al (2001) identified in an empirical study that there are many low activity performances influenced by and rooted from lack of maintenance. For instances, a number of work accidents caused by the improper condition of equipment or customer complaint due to bad quality of the product as the impact of the equipment's deterioration.

Every decision in business strategy will influence manufacturing behaviour, hence influences maintenance decision. This fact turns over the mindset of maintenance from an inevitable cost into an inseparable part of business competitiveness (Parida and Kumar, 2006). In the light of explanation on those paragraphs above, the importance of maintenance to business competitive achievement motivates an in-depth study. The relation of maintenance decision with manufacturing and business perspectives is proposed through an Integration of Maintenance Strategy and Operations (IMSO) approach. Although this approach will be applicable in different type of industry, this research is focussed in the automotive industry environment. The highly automated equipment in the automotive manufacturing system requires the bigger support of maintenance to produce high-quality vehicles which in turn significantly contributes to achieving enterprise competitiveness.

1.2 Statement of the Problem

To date, there are many studies which discuss the relation between manufacturing strategy and business competitiveness, such as analysing the importance of manufacturing strategy to the firm competitiveness (Avella et al., 2001), measuring the level of support of manufacturing for strategic objectives (Vickery et al., 1993), investigating the compatibility between manufacturing and business strategy in term of manufacturing flexibility (Chang et al., 2003) and its relation with business performance (Williams et al., 1995; Amoako-Gyampah and Acquaah, 2008; Sun and Hong, 2002), to name but a few. Nevertheless, the linkage of maintenance with manufacturing and business perspectives is still rarely discussed whereas the thought of the importance of maintenance as the business partnership has evolved recently. Since business strategy will lead the company to perform differently in achieving its competitiveness, it will influence the manufacturing process decision, then maintenance consequently. Thus, to ensure that the maintenance function is working in harmony, the formulation of maintenance strategy and operations in respect to manufacturing and business perspectives is an avoidable important issue.

The thoughts about the importance of maintenance contribution in achieving business goals have been proposed by many researchers in recent times (Pinjala et al., 2006; Pintelon et al., 2006; Swanson, 2001). Several attempts have been made in terms of coordinating maintenance decisions with business objectives. Moreover, the discussion of maintenance strategy is addressed to decide the best policy, concept and methodology to be aligned with manufacturing and to be linked to business strategy.

Some studies related to finding the obvious relation between maintenance strategy and competitive performance in practice are initially established through surveys. Swanson (2001) conducted a survey of maintenance management practices to identify the linkage of adopted maintenance strategy with the company's performance. She pointed out that proactive maintenance strategy and aggressive maintenance strategy were showing significant positive relationships with the performance of product quality, equipment availability and production cost.

Other surveys were held by Pinjala et al (2006) and Pintelon et al (2006). Pinjala et al (2006) identified the relationship between maintenance strategy and business strategy. This empirical investigation reveals that competitive priorities or business strategy elements of cost, quality and flexibility obviously influence the decision of maintenance strategy taken.

Meanwhile, Pintelon et al (2006) emphasized their survey on identifying and evaluating the effectiveness of maintenance strategy. They used Hayes and Wheelwright's (1984) four-stage framework, which are internal neutral, external neutral, internal supportive, and external supportive. The latter one is dedicated to the best maintenance practice. Each contributing company is evaluated on its maintenance function and then encouraged so their maintenance performance heading to the fourth stage descriptions.

Following those surveys, Salonen (2009) developed a work-process for the formulation of maintenance strategy through two criteria of maintenance performance, effectiveness and efficiency on the hierarchy level of strategic, tactical and operational. Meanwhile, Galar et al. (2011) and Kumar et al. (2013) proposed a maintenance metrics based on Balanced Scorecard (BSC) concept by emphasising the relationship of maintenance with other functions as well as the management hierarchy within the organisation. However, to figure out an integrated maintenance strategy and operations linked to manufacturing and business perspectives in order to support maintenance decision making through a hybrid Knowledge-Based System, a further study is required.

Another important aspect to be realized is considering the uniqueness system of every single company. As there is no single rule fit for every case, so there is no one best concept fit for every company (Mintzberg et al., 2003). Waeyenbergh and Pintelon (2002) argued that many maintenance concepts offered in literature are often time-consuming or only valid for some special industrial cases. Thus, immediate implementation of such particular maintenance concepts to assist maintenance works, unfortunately, is not followed by a satisfying result. They emphasized the importance of allowing the company to develop and customize its own maintenance concept linked to overall business performance. Some famous maintenance concepts such as Reliability-Centred Maintenance (RCM), Business-Centred Maintenance (BCM), or Total Productive Maintenance (TPM) are still valuable to give some insights and ideas in this context. Furthermore, instead of merely identifying maintenance criteria for a particular company, the formulation of maintenance strategy in this research is directed to be flexible to suit different companies and to accommodate any change when required.

Most of the maintenance strategy selections are conducted to answer the question of “What type of maintenance strategies will be applied in a particular industry?” and “What are the representative criteria addressed to decide the best-fit maintenance strategy?” However, the decision of maintenance strategy should not be fragmented and focused only on such narrow maintenance terms of corrective or preventive maintenance. It should be able to map a holistic requirement of maintenance to perform on its best circumstance as a driver of business success. Moreover, the new paradigm of maintenance strategy should be directed to face the question of “How to develop a maintenance system to achieve competitive advantages?” Of course, the answer not only lies on deciding to practice corrective, preventive or predictive maintenance, but it definitely has to consider workman skill of maintenance, maintenance organisation, maintenance inventory and other related factors simultaneously with respect of maintenance as a particular system.

Thus, the limitations of existing research and methods in maintenance strategy and operations have motivated this research to develop maintenance strategy and operations linked to manufacturing and business perspectives, with particular implementation in an automotive industry environment.

1.3 Aim and Objectives of the Research

This research is intended to find an approach that could accommodate the integration of maintenance with business and manufacturing perspectives to enhance maintenance performance as a business driver. The approach involves a computer programme that should be able to imitate the way of an expert in making a conclusion. Considering that requirement, a Knowledge-Based (KB) system as one of the artificial intelligence tools is used. This KB system is embedded with Analytic Hierarchy Process (AHP) and Gauging Absences of Pre-requisites (GAP) analysis to provide a powerful tool to support this research.

Based on the above problem statement, the aim of this research is to develop a Knowledge-Based System (KB) for Integrated Maintenance Strategy and Operations (KBIMSO) linked to manufacturing and business perspectives within an automotive industry environment. It constructs KB rules on business, manufacturing, and maintenance aspects. Each aspect contains KB rules attached with GAP analysis to assess the gap between current and prerequisite condition. AHP analysis is then deployed to compare those aspects structurally in a pair-wise manner to identify the critical ones to be rectified. Thus this hybrid KB system is used to evaluate maintenance performance and help to prioritise maintenance-related aspects to achieve the benchmarks.

In order to achieve the aim, the objectives of this research are as the following:

i. To detail literature review in the area of maintenance. It ascertains the current status of maintenance knowledge and practice. This will investigate elements of maintenance systems which influence maintenance decision making.
ii. To detail literature review in the area of manufacturing and business perspectives. It ascertains the current status of manufacturing and business

thinking related to maintenance function. This will identify the elements of business and manufacturing which contribute to develop an Integrated Maintenance Strategy and Operations (IMSO).

iii. To detail literature review in the area of Artificial Intelligence (AI), Knowledge-Based (KB)/Expert System (ES), GAP and AHP. It ascertains the recent development of AI, KBS/ES, GAP and AHP. This will support the design of the conceptual framework and the development of the Knowledge-Based for Integrated Maintenance Strategy and Operations (KBIMSO).

iv. To develop the KBIMSO framework. The KBIMSO framework is a type of knowledge acquisition which is generated from the collaboration of literature reviews as external input and personal intelligence as internal input. The KBIMSO framework identifies the important Key Performance Indicators (KPIs) in business, manufacturing, and maintenance which significantly contribute to maintenance decision making. Thereafter, the methodology used to implement the KBIMSO in order to support decision making for maintenance strategy and operations within automotive industry environment is presented.

v. To develop the KBIMSO model. This design focuses on generating and structuring the knowledge rules of the KB system. To find the gap between the existing system and ideal circumstance, and to accommodate multi-criteria analysis, the KB rules are embedded with GAP analysis and AHP technique.

vi. To develop the KBIMSO application. This development stage integrates all generated KB rules and methodologies into the KB shell to provide an interactive KBIMSO application. It facilitates the input collection, processes the data, and then provides the recommendation for a better maintenance strategy and operations decision.

vii. To verify and validate the KBIMSO and thereafter its refinement. Verification is conducted through assessing the accuracy of input information, output information, and justification of output (Awad, 1996). Verification of KBIMSO will be conducted along with validation by examining KBIMSO application through two industrial case studies and one published case study within automotive industry environment. The feedback from both the verification and validation is executed to refine the KBIMSO model and application. By the end of this step, it can be confirmed that the KBIMSO is reliable to provide a consistent and valid recommendation to support maintenance decision making.

viii. To conclude the work and result corresponded to the initial objectives, and propose some recommendations for future research.

1.4 Significance of the Research

The significance of this research is to advance the knowledge of the KB-GAP-AHP system to develop an Integrated Maintenance Strategy and Operations (IMSO) within automotive industry environment. As a logistic function of the manufacturing process, maintenance decision is complex in nature due to its dependency (Milana et al., 2014a). The developed hybrid KB system will assist decision making of maintenance strategy by consistently prioritising the critical aspects of maintenance performance to be considered in maintenance improvement plan. Embedding GAP and AHP into the KB system are intended to cover the complexity of various quantitative as well as qualitative elements of the system under study. Hence, the decision of maintenance strategy and operations can work in synergy with manufacturing function as a reflection of business strategy to achieve the business goal.

The developed KBIMSO is expected to:

- evaluate the current implementation of maintenance strategy and operations as a logistic function of manufacturing and as a derivation of business strategy.
- find the gap between existing implementation of maintenance strategy and operations with benchmarks.
- recommend the solution for closing the gap, as part of the decision making process.
- assist maintenance managers to formulate the relevant maintenance improvement plan based on the KBIMSO improvement recommendation.

The application of such KBIMSO approach is likely to be applied widely in the different types of industry. But, this study is validated empirically within the automotive industry. The automotive industry is chosen for the reasons of its special characteristics. Firstly, the development of such industry emerges significantly and competitively and influences national economic growth, with the high innovation of product and technology. Applying an approach to improve its manufacturing performance always becomes an interesting issue. Secondly, the manufacturing process of the automotive industry is known for characteristics of flexibility, high automation, advanced technology and agile process. The manufacturing process for different types of products in the same production line requires flexibility to switch product type based on demand (Goyal et al., 2012). Overall, it can be said that its high level of technology and automation show the high connection between business and manufacturing with maintenance performance. By applying the KBIMSO in this type of industry, the impact of the KBIMSO can be clearly detected and identified.

1.5 Methodology of the Research

This research is started with literature review in some areas to cover research needs. Then, the research activities are continued with the development of KBIMSO framework, KBIMSO model and KBIMSO application. Figure 1-1 presents the methodology path of this research to show the systematic flow to develop the KBIMSO.

The research initially investigates three main groups of the literature review. The first group discusses maintenance to ascertain its definition, function, some policies, and some popular concepts. The second group encompasses literature review of maintenance strategy and operations, and its relation to manufacturing and business perspectives. The last group of literature review covers the areas of Artificial Intelligence (AI) with respect to KBS/ES, GAP and AHP analysis to ascertain the role of those techniques in building up the KBIMSO.

By identifying the elements of business, manufacturing, and maintenance that contribute to maintenance strategy and operations decision making, a KBIMSO framework that depicts the interrelation of them will be developed. The generating process of contributed elements is critical since the small number of elements would not enable represent the overall system, whilst considering all possible elements would be too complex and overlapping (Wibisono, 2003). In turn, not only showing the relation among those elements, the proposed framework also contains the methodology used to develop the KBIMSO and implementation alternatives.

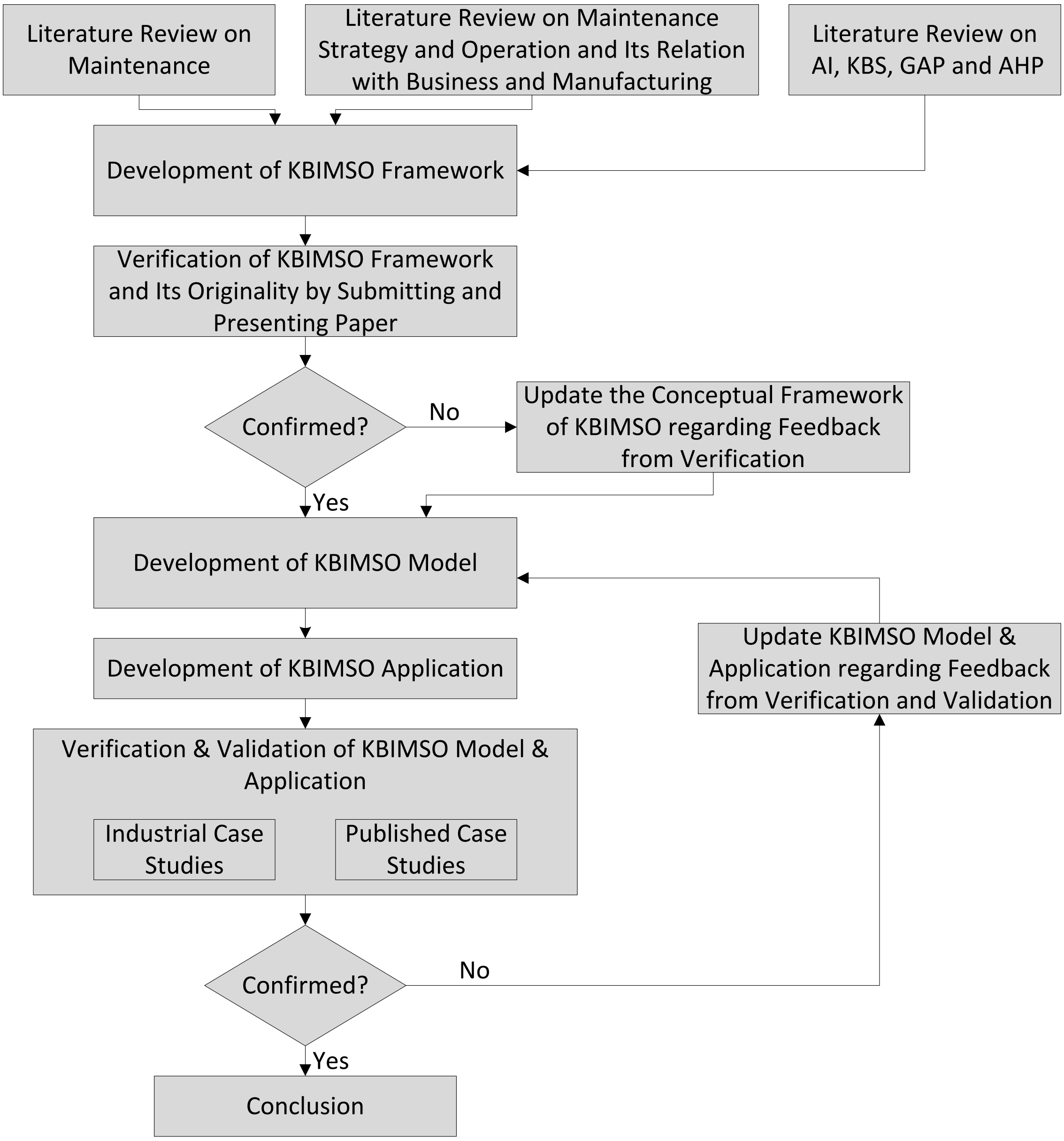


Figure 1-1 Methodology path of research

Once the KBIMSO framework is developed, the verification of such framework and originality of research is confirmed through peer-review by submitting a paper and presenting it at a conference. Therefore, the academic experts and other audiences in the similar interest might assess the originality of this research, justify the stages and procedures for developing the framework, and also give suggestions to improve the KBIMSO framework. After this step is confirmed, the KBIMSO model is started to develop.

In the development of KBIMSO model, KB rules are generated for each element of the KBIMSO. This is the key part of this research. Each KPI on business, manufacturing and maintenance aspects is represented through a set of KB rules within the KBIMSO. There will be approximately 2000 to 2500 KB rules developed to support decision making process within the KBIMSO. The development of KB rules is supported by published articles related to maintenance strategy and operations, the relationship between maintenance with business and manufacturing strategies, KB system, GAP, and AHP. The regular discussion with supervisors is also another method to develop the KB rules.

This stage also presents the methodology used on the KBIMSO which embeds GAP and AHP into the KB system. GAP analysis is used to identify the gap between current state and the benchmark. To achieve the optimal results, GAP analysis should be arranged in a structured and hierarchical format (Mohamed, 2012). Meanwhile, AHP enables the KBIMSO to deal with unstructured and complex considerations thus detailed analysis can be conducted for both quantitative and qualitative variables. In this research, AHP links and weights the KBIMSO elements consistently to get prioritisation on maintenance strategy and operations decision.

Verification and validation of the developed KBIMSO model and application are conducted simultaneously with industrial and published case studies. The purpose of verification is to assess whether the KB system is working as expected on its internal procedure and calculation. While the validation is intended to ensure that the KBIMSO can propose recommendation as the way of experts do so. The verification and validation of the KBIMSO are conducted after entire KBIMSO model and application have been developed where every changing is then made when necessary. The revision of KBIMSO based on feedback from practitioners is managed during this process. After the result obtained and the KBIMSO model is verified and validated, the conclusions can be reached.

1.6 Thesis Outline

This thesis consists of nine chapters, as shown in Figure 1-2. Chapter 1 encompasses background of the research, statement of the problem, aim and objectives of the research, significance of the research, and methodology of the research. The thesis outline is included at the end of this chapter to provide an overview of the whole thesis.

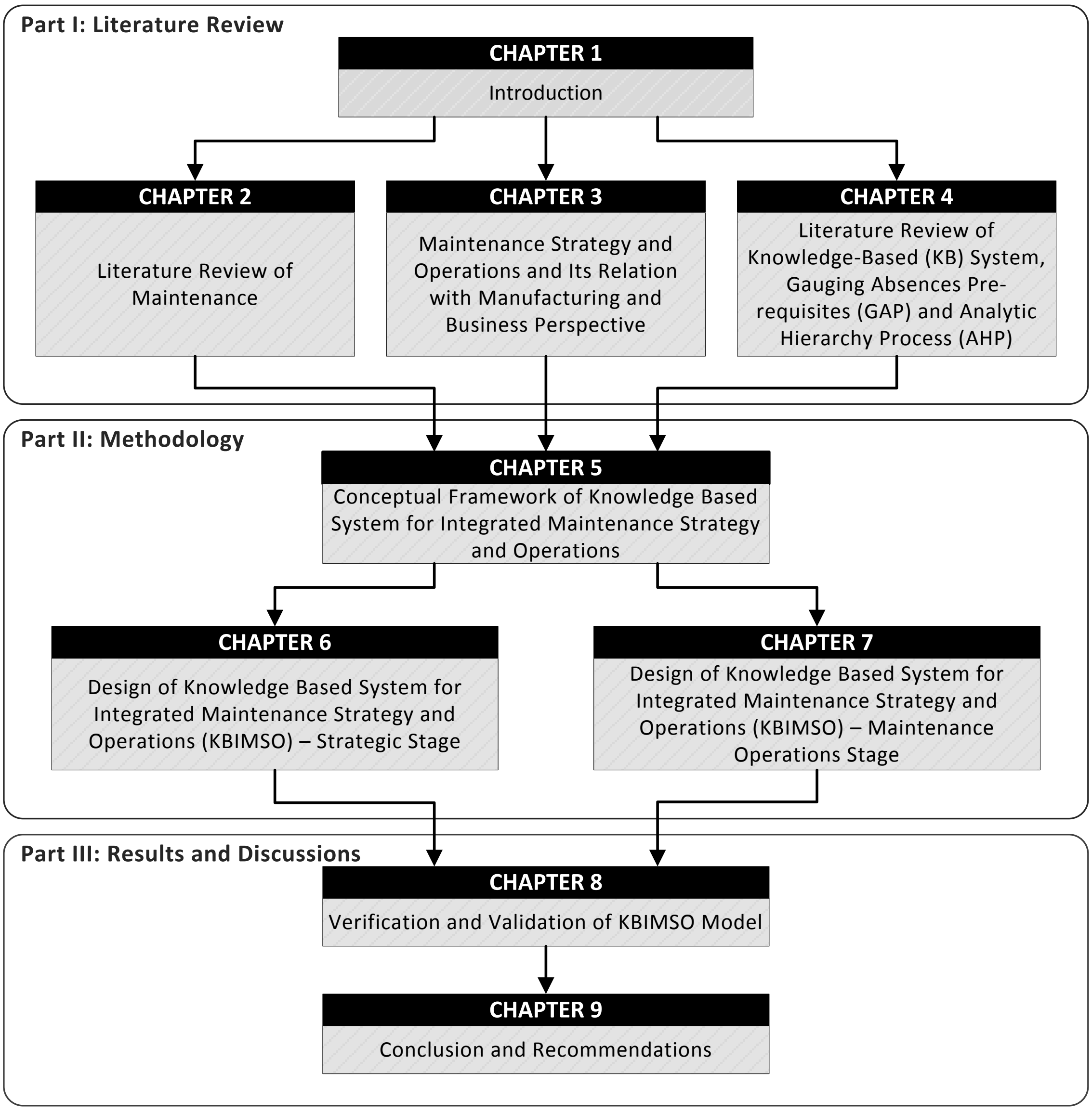


Figure 1-2 Summary of research activities

Chapter 2 presents the literature review of maintenance from a general perspective. It discusses the definition of maintenance, maintenance function, maintenance policy and some maintenance concepts. This topic is required to gain an understanding of maintenance system, thus the KBIMSO could accommodate critical factors which influence maintenance performance.

Chapter 3 focuses the literature review of maintenance strategy and operations, and the importance of integration of maintenance with business and manufacturing aspects. This discussion is also required to understand the interaction pattern of maintenance, manufacturing and business which influence maintenance decision making.

Chapter 4 reviews the literature about the tools to support the development of KBIMSO. It is started from a general discussion of AI and some branches of AI. Later, the specific discussion is detailed to KB System/Expert System as the suitable tool to use on this research. To get insight about the hybrid KB system deployed in this research, the discussion of GAP and AHP is also included.

Chapter 5 explains the development process of the KBIMSO framework. This chapter explores each stage on the KBIMSO framework. The important aspects of business, manufacturing, and maintenance itself are highlighted as well as other stages in this KBIMSO framework. Furthermore, the structure of KBIMSO model is presented together with the explanation of supporting techniques to develop the KBIMSO.

Alter presenting the KBIMSO structure in Chapter 5, the explanation about the development of KBIMSO model and KBIMSO application is detailed in Chapter 6 and 7. Chapter 6 focuses on developing *Strategic Stage* of KBIMSO. On this stage, the KB rules proceed to be generated on each aspect of the KBIMSO. The *Strategic Stage* includes *Company Environment* (Level 0), *Business Perspective* (Level 1), and *Manufacturing Perspective* (Level 2).

Furthermore, Chapter 7 details the development of KBIMSO model and KBIMSO application on *Maintenance Operations Stage*. It included *Maintenance Rules* (Level 3), *Maintenance Activities* (Level 4), and *Maintenance Resources* (Level 5). These two chapters also cover the integration of GAP analysis into the KB system.

Chapter 8 focuses on the process of verification and validation of the KBIMSO model. This chapter explains verification and validation steps on industrial and published case studies which involve AHP analysis.

Finally, Chapter 9 presents the conclusion of the research. The discussion includes research achievement, advantages of the KBIMSO, limitation of the research, and recommendations for future work.

1.7 Summary

This chapter has presented the basic background that motivated this research. The discussion has proceeded from the shift of traditional to modern maintenance perspective which increases the role of maintenance towards business competitiveness. Considering the importance of maintenance decision making to integrate with manufacturing and business aspects, this research focuses on the development of Integrated Maintenance Strategy and Operations (IMSO) by using the hybrid KB System/GAP/AHP methodology. After stating the research aim, the research objectives, and the signification of this research, the research methodology is explained. Thesis outline is presented at the end of this chapter to give an overview of research from the early stage (research background) until the last stage where the aim and objectives are achieved.

CHAPTER 2

Literature Review of Maintenance

2.1 Introduction

The aim of maintenance is to keep the equipment working on its specified function. To achieve this aim, the maintenance system has some elements which have to work in harmony. These are maintenance activities, maintenance resources, maintenance rules, maintenance performance, and maintenance control which are involved in maintenance systems to support overall maintenance performance.

Each maintenance policy represents different characteristics of maintenance. The selection of maintenance policy depends on the characteristics of the manufacturing equipment and manufacturing process. Meanwhile, maintenance concept offers a different approach in performing maintenance tasks with a certain set and structure of maintenance policies. To provide a more detailed explanation about maintenance, this chapter encompasses the literature regarding the definition of maintenance, the function of maintenance, maintenance policies, and some maintenance concepts.

2.2 Definition of Maintenance

Maintenance is considered as all actions taken to retain an equipment in or restore it to a given condition (Dhillon, 2002b). Generally, many kinds of literature also define maintenance in much a similar way. British Standard BS EN 13306:2010 (2010) explained that maintenance is:

> *"combination of all technical, administrative and managerial actions during the life cycle of an item intended to retain it in, or restore it to, a state in which it can perform the required function".*

Duffuaa et al (1999) defined maintenance as:

> *"the combination of activities by which equipment or a system is kept in, or restored to, a state in which it can perform its designed functions".*

Another closed term to explain maintenance is reliability. Reliability is the probability of the equipment to work at its expected performance during a specified time period (Gulati, 2013). Maintenance is also defined from a failure perspective. Failure is simply defined as the inability of a piece of equipment, a plant, or a system to work at its expected performance (Smith and Hinchcliffe, 2004). Therefore, the existence of maintenance is considered to increase reliability, prevent failure or take the countermeasure to minimise the impact of equipment failure, enhance manufacturing process and environment, and in turn, influence business prospective.

All of these definitions always refer to the combination of efforts given to ensure the equipment can work at its expected function. As a conclusion, maintenance is referred to as a combination and integration of activities, resources and rules to achieve its aim to retain expected equipment performance. By the existence of a specific intention, maintenance elements, and interaction of these elements to meet the intention, maintenance can be considered as a particular system in a company. Discussion of maintenance as a system is important to consider the proper requirements of maintenance as the function to support manufacturing equipment reliability.

An effective maintenance system should have a good relation among its elements to perform a seamless operation. The key elements of maintenance and the relationship among them are presented in Figure 2-1. Maintenance activities specify activities required, where and when they are performed (Duffuaa et al., 1999). Maintenance resources are related to personnel, tools, material, and ICT needed. Maintenance rules are pointed to policy, organisation and coordination, and how to execute the maintenance tasks. Maintenance rules also correspond to information and documentation flow, either to the internal maintenance member, or the external department such as manufacturing or quality department. Maintenance system operation should be accompanied by maintenance performance measurement as the competitive way to ensure that maintenance performance can meet the expected standard. After all, monitoring and control are executed along with all processes to obtain feedback as a reference for continuous improvement.

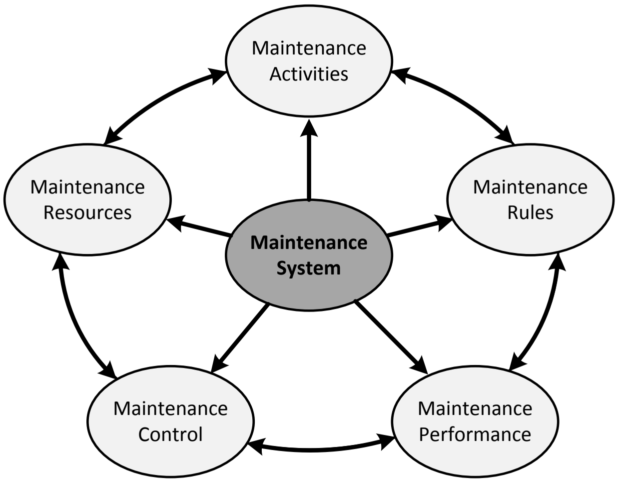


Figure 2-1 Elements of an effective maintenance system

To implement an effective and holistic maintenance system, those elements should be included and addressed properly. Later on, these elements and their interaction are included in the developed framework of the KBIMSO within this research as the way to present a representative picture of maintenance system.

2.3 Maintenance Function

Initially, maintenance was just focused on correcting and repairing machines; where the maintenance personnel would start their task once the equipment broke down. As a consequence, the cost of correction was high and maintenance was always judged as a “necessary evil”. On the contrary, maintenance is now considered as another important driver to achieve business competitiveness.

Maintenance functions to ensure and control reliability of the plant (Kelly, 1997). Effective maintenance can extend equipment life, improve equipment availability and retain equipment in proper condition (Swanson, 2001). Identifying the detailed functions of maintenance will assist a company to decide the expected performance and to allocate the resources required by maintenance to perform its tasks appropriately. The technical functions of maintenance are detailed as the following:

a. Retaining equipment to ensure that it works to its expected performance.
   These basic activities are performed regularly on daily bases, such as lubrication, cleaning, inspection and adjustment (Duffuaa et al., 1999). This maintenance function can be done by the operator of the manufacturing

equipment during the operation of their machine. These are very beneficial to keep the satisfactory operation of equipment and to avoid major failure (Dhillon, 2002b).

b. Repairing the deterioration of equipment to return it to its desired performance.

   As a responsive action, the restoring activities are applied by prioritising the failure impact to the overall manufacturing process and its potential domino effects.

c. Modifying equipment to prevent failure.

   The role of maintenance to get involved in modifying equipment is influenced by the evolving of Total Productive Maintenance (TPM) concept to avoid failure.

d. Designing equipment or a set of equipment that is suitable for the operating conditions and operating requirement of a manufacturing function.

   Similar to the role of modifying equipment, the maintenance activity of designing new equipment emerges through TPM concept. Both modification and design activities require a multidiscipline teamwork from maintenance, manufacturing, and engineering.

The latter two functions above are known as part of aggressive maintenance policy that is discussed later in Section 2.4.4. These activities are usually not conducted in every company, but depend on how complex the manufacturing process is and how big the concern of the company is to consider maintenance function as a competitive advantage. But, to make those activities run smoothly in order to ensure equipment optimality, there are some complementary functions required, as the following (Dhillon, 2002b):

- To decide the proper maintenance policy for different criteria of equipment
- To calculate cost allocation for maintenance resources
- To document all equipment operating records and its maintenance treatments
- To monitor and improve maintenance personnel performance
- To get involved in deciding and installing new plant facilities or equipment
- To manage inventory of maintenance
- To prepare realistic budgets for personnel and inventory of maintenance

2.4 Maintenance Policy

Reactive/corrective maintenance, preventive maintenance, predictive maintenance, and other similar maintenance terminologies are often misused in many kinds of literature as maintenance strategy since they are related to the treatments and policies used to maintain equipment. In fact, maintenance strategy is more than that narrow perspective. It should cover a holistic element to support maintenance performance in order to achieve a business goal. Therefore, hereafter the term of maintenance policy will be used to mention corrective maintenance, preventive maintenance, and other related terms.

Generally, maintenance policies are only distinguished by corrective and preventive maintenance. Smith and Hinchcliffe (2004) defined this as *unplanned* and *pre-planned maintenance*, respectively. But, the different treatments given to preventive maintenance distinguish such maintenance policy into time-directed, condition-directed, failure-finding and run-to-failure. BSI Standards Publication (2010) differentiated preventive maintenance into condition-based and predetermined maintenance. However, other authors classify maintenance policies in different ways. Bevilacqua and Braglia (2000) classified five types of maintenance policies, which are corrective, preventive, predictive, condition-based and opportunistic maintenance. Swanson (2001) noted three general types of maintenance policies; reactive maintenance, proactive maintenance which is classified into preventive and predictive maintenance, and aggressive maintenance. By summarizing these notions, Figure 2-2 shows the classification of maintenance policies which then will be reviewed to compare and contrast each of them.

Considering the different characteristics of each machine such as productive age, its significance to the overall process, safety, cost, and resources allocation, the combination of maintenance policies is commonly applied. Grouping equipment based on a particular maintenance policy will improve effectiveness and efficiency to achieve company competitiveness (Bevilacqua and Braglia, 2000; Arunraj and Maiti, 2010). Therefore, those maintenance policies are discussed below to understand the suitable circumstance for each policy to be applied.

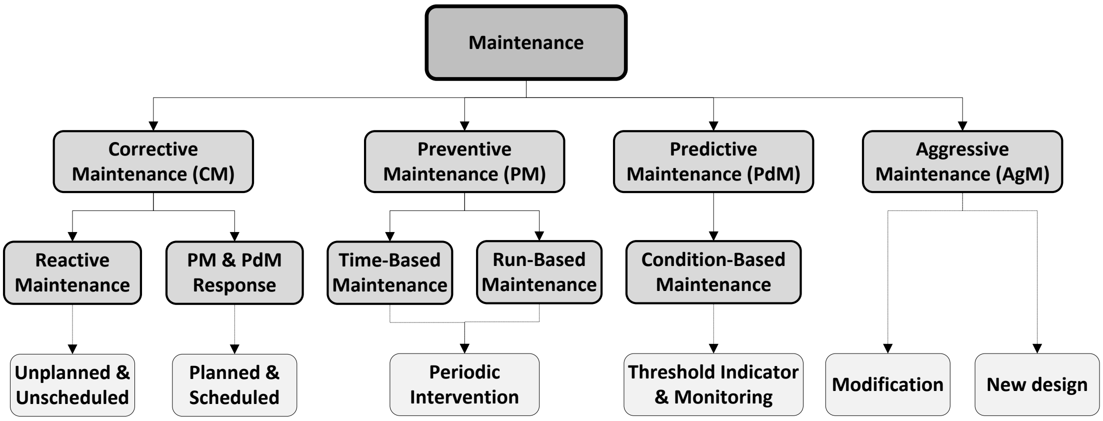


Figure 2-2 Classification of Maintenance Policies

2.4.1 Corrective Maintenance

Corrective Maintenance (CM) was generally known as reactive maintenance which focuses on repairing the breakdown in unplanned maintenance (Swanson, 2001). It was also known as “fix when it breaks”, “fire-fighting”, or “run-to-failure”. It means there will be no intervention to operation process before failure. Reactive maintenance is considered to save maintenance manpower and budget spent to keep the reliability of equipment. Unfortunately, this policy leaves unpredictable breakdown of equipment which leads to decreasing manufacturing productivity, decreasing quality, and increasing product lead time, as an indication of weak business competitiveness. The secondary effect due to failure also causes overtime for unscheduled work (Gulati, 2013). This unplanned corrective maintenance causes a company to spend on corrective cost as much as 80% of the maintenance and operation budget to fix the chronic failure of machines, systems and people (Dhillon, 2002b). In another reference, Mobley (2004) claimed that the corrective maintenance cost is three times higher than scheduled maintenance cost.

For these reasons, unplanned maintenance has been left discarded and corrective actions then are only treated in the frame of planned maintenance when malfunction and breakdown of equipment are still occurring. It means that planned corrective maintenance is required as a response to monitoring of equipment condition (Gulati, 2013).The activities of corrective maintenance are classified into fail-repair, rebuild, overhaul, salvage, and servicing (Dhillon, 2002b).

2.4.2 Preventive Maintenance

The main aim of Preventive Maintenance (PM) is avoiding equipment deterioration to prevent breakdown or reduce the probability of failure (Swanson, 2001). Duffuaa et al (1999) explained this intention as ensuring availability and reliability of manufacturing equipment. Availability refers to the probability of equipment to be ready to use when required and reliability refers to the probability of equipment to work properly during the expected time. To perform preventive maintenance, Dhillon (2002b) identified seven main activities to be conducted, those are inspection, servicing, calibration, testing, alignment, adjustment, and installation. The main difference of this policy from corrective maintenance is its pre-planned maintenance action instead of unplanned maintenance (Smith and Hinchcliffe, 2004). It is the way to increase equipment productive life, reduce equipment breakdown, reduce scrap and rejected product, reduce idle operator time, reduce repairing cost, and promote health and safety of maintenance personnel. Preventive Maintenance is taken based on the reliability characteristic of components that enables the maintenance engineer to plan and schedule regular checking and reconditioning (Bevilacqua and Braglia, 2000).

The maintenance activity using PM is performed in a specified time interval, such as daily, weekly, or after any particular activity. Therefore, this policy is also known as Time-Based Maintenance (TBM). The availability of sufficient historical data, decision support systems, and standard deviation of failure time influence the success of this maintenance policy (Al-Najjar and Alsyouf, 2003).

Tsang (2002) noted that TBM is performed periodically regardless of the machine's actual condition. The action will be continuously held without the deterioration indication exist (Smith and Hinchcliffe, 2004). As a consequence, such maintenance policy commonly interrupts the manufacturing process at its scheduled time to perform the work. However, for the equipment which is not used periodically, implementation of time-based maintenance is considered as a waste of time and resources. There is no need to check such equipment as many as other assets which are used routinely. Therefore, to obtain a better preventive maintenance, Run-Based Maintenance (RBM) comes as an option for particular equipment (Gulati, 2013). By following the same rule as time-based maintenance of which the equipment is checked periodically, run-based maintenance reviews equipment condition after reaching a specified threshold, after a certain number of rotations or a certain distance.

The required maintenance actions range from a minor adjustment which is cheap and quickly such as cleaning and lubrication, to a complex overhaul which is expensive and time-consuming. Since there will be the possibility of intrusion of equipment, implementation of such policy is not very popular. Unless the overhaul is important for maintaining the performance of critical equipment that influences overall manufacturing process, most of PM actions are limited to minor inspection and adjustment. To detect any potential failure, other policies such as predictive maintenance or condition-based maintenance are proposed to be applied.

2.4.3 Predictive Maintenance

Tsang (2002) argued that the reason for Predictive Maintenance (PdM) is to avoid excessive treatment of preventive maintenance that may replace equipment prematurely. Therefore, this policy is also known as Condition-based Maintenance (CBM). The aim of PdM is avoiding failure to occur through threshold indicators and monitoring. Once the threshold is achieved, the information is sent to maintenance personnel as a message that deterioration is in progress. PdM requires both sets of measurement and data availability to monitor machine performance (Bevilacqua and Braglia, 2000). Afterwards, these collected data are employed to determine the probability of equipment condition and potential failure through the pattern and trend analysis, correlation of multiple technologies, data comparison, statistical process analysis and test against limits and ranges so replacement is only treated just before failure (Dhillon, 2002b; Al-Najjar and Alsyouf, 2003). The pattern obtained will inform any abnormal situation and lead to action of fixing or stopping the machine. Performance-parameter analysis such as vibration monitoring, thermography, sonic and ultrasonic, infrared, oil analysis and ferrography are some of the condition monitoring techniques that support PdM.

2.4.4 Aggressive Maintenance

Aggressive Maintenance (AgM) is generated from the Total Productive Maintenance (TPM) approach (Swanson, 2001). This policy focuses on modifying or designing the manufacturing equipment. Although having a similar aim with other policies to avoid failure, the effort given is different. In AgM, the new or existing equipment is modified or designed by a multi-disciplined team. This team may involve personnel of maintenance, manufacturing and engineering that vary from operators to managers. The newly designed equipment is supposed to have a predominance of high reliability, high maintainability, low maintenance resource equipment and low routine servicing (Tsang, 2002).

According to the different characteristics of each policy, some or all maintenance policies could be applied simultaneously by respecting to the equipment requirement and business competitive capability. Equipment or a cluster of equipment will be treated with different configuration and proportion of maintenance policies. Thus the combination of maintenance policies can gain optimal maintenance performance. To ease comparing the maintenance policies explained above, their characteristics are summarized in Table 2-1.

Table 2-1 Comparison of maintenance policies

Criteria	Corrective Maintenance	Preventive Maintenance	Predictive Maintenance	Aggressive Maintenance
Interruption to the operation process	No	High	Low	Low
Maintenance planning	Unplanned	Planned	Planned	Planned
Maintenance cost	High	Low	Low	Low
Investment cost	No	Low	High	High
Inventory cost	High	Low	Low	Low
Failure rate	High	Low	Low	Low
Risk to quality	High	Low	Low	Low
Consideration for implementation	Suitable when maintenance cost is higher than risk and failure cost	Sufficient historical data, small standard deviation of time between failure	Availability of monitoring tools to detect abnormalities, intervention of preventive maintenance is less effective regarding risk and cost	Work collaboration from different functions

Although retaining and repairing activities are intended to maintain manufacturing equipment performance, the run-to-failure approach is considered as the last maintenance option. When the equipment has been used for a certain period and has reached its expected productive age, maintenance treatments for such equipment will result in a financial loss. Run-to-failure is a conscious decision for equipment of which its maintenance cost is bigger than its risk and failure cost (Dhillon, 2002b).

2.5 Maintenance Concepts

To assist the maintenance activities to work properly, maintenance managers usually refer to a particular maintenance concept. Maintenance concept is a term used to describe a set of maintenance policies (corrective, preventive, predictive and aggressive) in a certain structured implementation in which these tasks are foreseen (Waeyenbergh and Pintelon, 2002). It is intended to emphasise some maintenance performances in order to achieve its aim. The important point to note is that maintenance concept is not always suitable for every type of company and industry. But, absorbing the essence of every single concept can be powerful to gain a customised concept that suits different companies. Every maintenance concept has different credit values as discussed below.

2.5.1 Reliability-Centred Maintenance

Reliability-Centred Maintenance (RCM) initially is a term used as a title for a report of maintenance programme for aircraft in the civil aviation industry (Dhillon, 2002b). It evolved as a maintenance concept that provides a structure for determining the maintenance requirement of physical assets by considering cost-effectiveness (Tsang, 2002). Thus, instead of bringing equipment into ideal condition, the basic concept of RCM is directed to restoring equipment function in order to gain high reliability and availability (Duffuaa et al., 1999). The overall basic process of RCM is shown in Figure 2-3.

RCM analysis is marked by a Failure Modes Effects and Criticality Analysis (FMECA) to identify the system function and functional failures. Then, the Fault Tree Analysis (FTA) is used to integrate all decision process into a single strategic framework (Waeyenbergh and Pintelon, 2002).

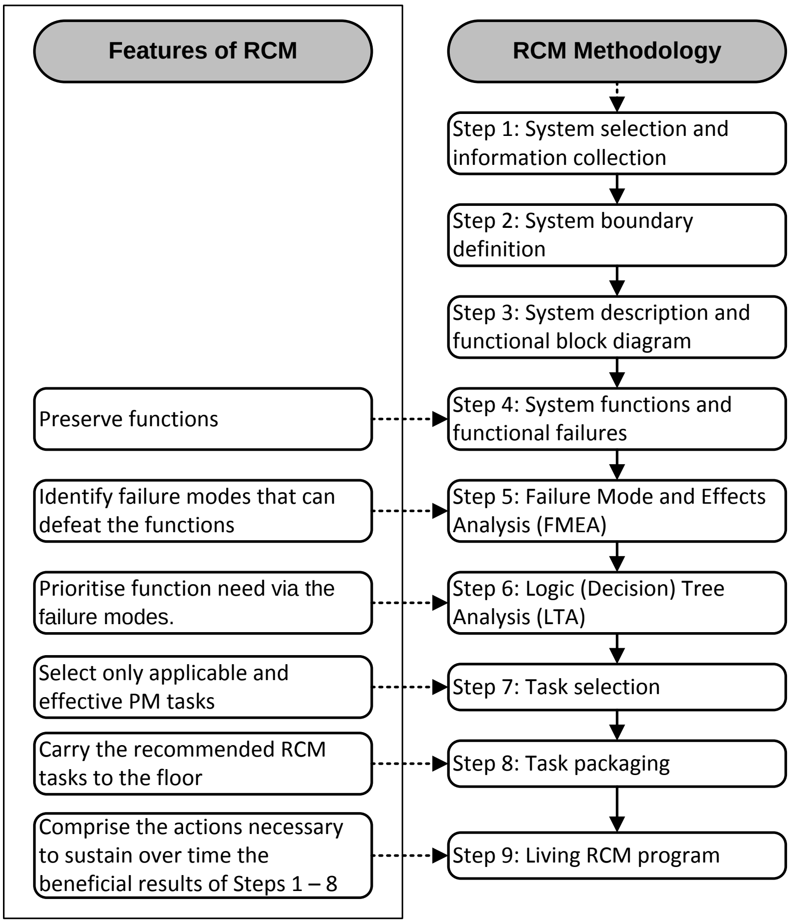


Figure 2-3 Basic process of Reliability-Centred Maintenance, adapted from Smith and Hinchcliffe (2004)

Unfortunately, this kind of approach is criticised as labour intensive, time-consuming and costly so it should be implemented selectively to high-risk or over maintained systems to get the positive ratio of benefit-cost (Tsang, 2002). Picknell and Steel (2005) claimed that RCM will create benefit only for a company that has breakdown account more than 20 to 25% of the total maintenance workload.

2.5.2 Total Productive Maintenance

The aim of Total Productive Maintenance (TPM) concept is eliminating the waste of faults of equipment. It is rooted in Total Quality Management (TQM) that focuses on equipment management to improve quality through people as the driver of improvement (Duffuaa et al., 1999; Tsang, 2002). Thus, the continuous improvement is emphasized on Overall Equipment Effectiveness (OEE) as criteria to address availability, speed and quality performance (Waeyenbergh and Pintelon, 2002).

Some principles of TPM are as follows (Tsang, 2002):

a. The operators take responsibility for the primary care of their plants such as cleaning, routine inspection, lubrication, adjustment and minor repairs.
b. Maximizing operation effectiveness by improving operators' skill and knowledge to enable them to detect early sign and make improvement suggestion.
c. Develop a cross-functional team of operators, maintainers, engineers and managers to improve equipment performance.

2.5.3 Business-Centred Maintenance

Business-Centred Maintenance (BCM) is a new concept in maintenance strategy developed by Kelly (2006) which was explained in his book of "Strategic Maintenance Planning". This is an approach in which competitive strategy is placed on the top of the hierarchy to be disaggregated into functional strategies on well-administrative management. His thought is in-line with the statements of some researchers such as Parida and Kumar (2006) and Sharma et al (2011), who noted about the transformation of maintenance from important function to a business partner. As consequence, formulation of maintenance strategy will refer to business strategy to gain a competitive advantage. Waeyenbergh and Pintelon (2002) pointed out the objectives of BCM to maximize profit, instead of focusing on technical performance as proposed by RCM. The methodology of BCM is depicted in Figure 2-4.

This cycle is provided as the guidance to decide maintenance objectives based on business objective and manufacturing objective. It is then directed to formulate equipment life plants and maintenance schedule, specify the workload and budget, organise the resources, and determine the policies. The plant layout and the dedicated labours are discussed in resource structure, while the workload is planned, scheduled and controlled in the work planning system. Meanwhile, the hierarchy of maintenance labour in term of their authority and responsibility to make maintenance decision is decided in administrative structure. Those activities are represented by a report and control of the entire processes for correcting and refining the maintenance objective with respect to continuous improvement.

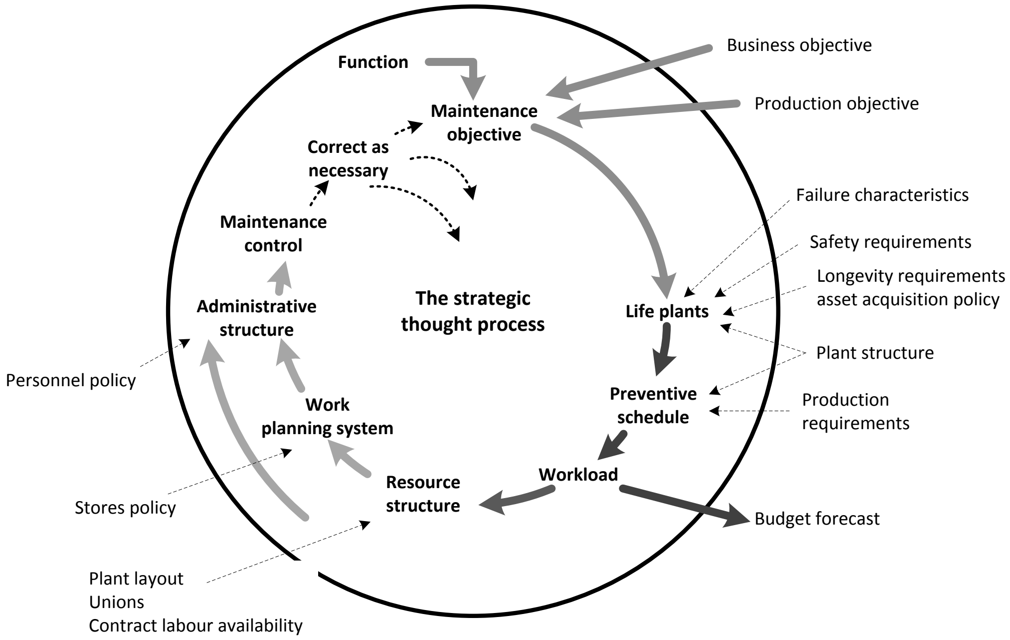


Figure 2-4 Business-Centred Maintenance methodology (Kelly, 2006)

Unfortunately, the execution of maintenance decision into each facility is claimed to make this approach cumbersome and complicated (Waeyenbergh and Pintelon, 2002). Furthermore, they argued that implementation of such concept is merely suitable for a special class of equipment or a specific industry. However, there are some similarities between BCM and KBIMSO, where business and manufacturing concerns are involved to support maintenance decisions.

2.6 Chapter Summary

Maintenance is defined as the combination and integration of activities, resources, and rules to achieve its aim to retain expected equipment performance. As an individual system, maintenance has some elements to achieve its goal; those are maintenance activities, maintenance rules, maintenance performance, maintenance control, and maintenance resources. To obtain the effective maintenance system, each element of such system should be integrated and work together to perform the seamless operation.

The consciousness about the contribution of maintenance to achieve business competitiveness has grown rapidly. As the logistic function to support manufacturing process, maintenance function can extend production equipment life and maintain product lead time and quality. The activities of maintenance emerge from repairing and retaining equipment performance to modify and design for easy-maintainability equipment. However, the maintenance policy and maintenance concept used in the company influence the range of maintenance activities applied.

There are some maintenance policies identified, which are corrective maintenance, preventive maintenance, predictive maintenance, and aggressive maintenance. Meanwhile, there are some types of maintenance concepts which also contribute to the implementation of maintenance. Some of them are Reliability-Centred Maintenance, Business-Centred Maintenance and Total Productive Maintenance. Each maintenance policy and maintenance concept has different characteristics with its strength and weakness to suit the different type of business orientation and manufacturing process. In summary, the combination of maintenance policies and concepts need to be explored to design maintenance strategy and operations. To discuss the requirements for integrating maintenance with business and manufacturing, Chapter 3 reviews the literature about maintenance strategy and operations and its relation to manufacturing and business perspectives.

CHAPTER 3

Maintenance Strategy and Operations and its Relation to Manufacturing and Business Perspectives

3.1 Introduction

The main important step for a company to achieve its goal is to “get it acts together” (Hayes et al., 2005). It means all elements in the entire company should work in the right manner and the same direction to ensure that they come out as a synergy to attain the competitive advantages. The point that should be considered is that the company has a different level of strategies with different roles on each level, which are corporate strategy, business unit strategy and functional strategy (Hill and Hill, 2009) as shown in Figure 3-1.

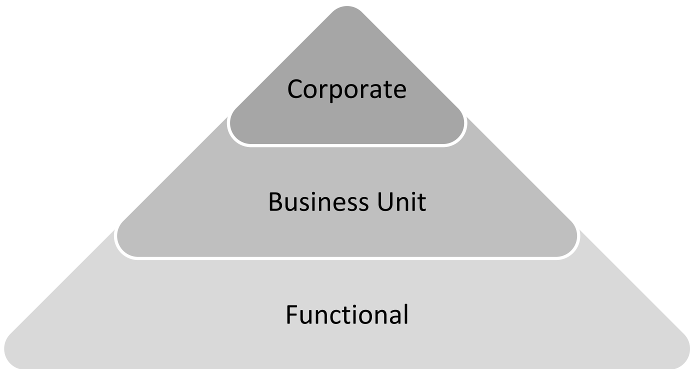


Figure 3-1 Levels of strategy in the company

Corporate level concerns on business placement in the industry regarding the decision of what kind of product, what and where to invest, and financial achievement estimation. To manage a different business in a company, some business units are assigned. One business unit is intended to manage one market in which it competes, decide competition criteria, and identify potential market share for future growth. In this level, corporate issues related to product development and investments are continuously discussed. The bottom level concerns with functional sectors. They play operational activities to fulfil competitive dimensions which have been formulated, where each function will interact horizontally with other functions and vertically to upper levels.

According to the aim of this research, the IMSO will consider the related aspects of business perspective on the business unit level, as well as manufacturing and maintenance perspectives on the functional level. Some important aspects of manufacturing and business perspectives are discussed in this chapter along with the interaction pattern of them with maintenance.

3.2 Maintenance Strategy and Operations

The issue of connecting maintenance strategy with business and manufacturing strategy has evolved along with the consideration of maintenance as the partner to achieve business objectives. The role of maintenance as profit contributor leads to the need for a coherent strategy from business strategy. Unfortunately, the terminology of strategy can be very confusing. To date, there are many definitions offered by researchers to represent what exactly maintenance strategy is. Thus, once it is determined, the remaining path will be much clearer to be directed. Pinjala et al (2006) defined maintenance strategy as:

> *"Coherent, unifying and integrative pattern of decisions in different maintenance elements in congruence with manufacturing, corporate and business level strategies; determines and reveals the organizational purpose; defines the nature of economic and non-economic contributions it intends to make to the organization as a whole."*

A maintenance concept can be developed by considering related factors holistically (Waeyenbergh and Pintelon, 2002). In the light of this point, factors that represent maintenance itself, the interrelation of maintenance with other functions and interrelation of maintenance with general organisational structure should be taken in developing a proper maintenance strategy. As maintenance function is situated in the lower level of the business hierarchy, its strategy and operations should be clearly defined simultaneously as part of the corporate system to achieve the goal. Performance of maintenance strategy might be measured by product quality, equipment availability and production cost (Swanson, 2001) which indicate the connection between maintenance and manufacturing function.

Hayes et al (2005) and Pinjala et al (2006) generally promoted the reinforcement of structural and infrastructural elements to support strategy and operations as shown in Table 3-1.

Table 3-1 A summary of maintenance strategy elements (Pinjala et al., 2006)

STRUCTURAL	
Elements	Sub-elements
Maintenance capacity	Capacity in term of workforce, supervisory and management staff. Shift patterns of workforce, temporary hiring of workforce
Maintenance facilities	Tools, equipment, spares, workforce specialisation (mechanics, electricians, etc.), location of workforce
Maintenance technology	Predictive maintenance, or condition monitoring technology, expert systems, maintenance technology (intelligent maintenance)
Vertical integration	In-house maintenance versus outsourcing and relationship with suppliers
INFRASTRUCTURE	
Elements	Sub-elements
Maintenance organisation	Organisation structure (centralised, decentralised, or mixed), responsibilities
Maintenance policy and concepts	Policies like corrective, preventive and predictive maintenance. Concepts like Total Productive Maintenance, Reliability-Centred Maintenance
Maintenance planning and control systems	Maintenance activity planning, scheduling. Control of spares, costs, etc. Computerised Maintenance Management Systems
Human resources	Recruitment policies, training, and development of workforce and staff. Culture and management style
Maintenance modifications	Maintenance modifications, equipment installations and new machine design support
Maintenance performance measurement and reward systems	Performance recognition, reporting and reward systems, Overall Equipment Effectiveness and Balanced Scorecard

Structural elements consist of buildings, equipment, and contractual obligations. On the other hand, policies, practices, and systems are grouped within the infrastructural elements. These elements and sub-elements are useful to assist the formulation of maintenance strategy and operations.

Meanwhile, Tsang (2002) noted the elements of maintenance strategy that supports maintenance. Those are service-delivery options that choose between in-house capability and outsourced service, organisation of the maintenance task and function, maintenance policy and infrastructure. These elements come as inputs into the maintenance system which provides output for the overall company, as shown in Figure 3-2.

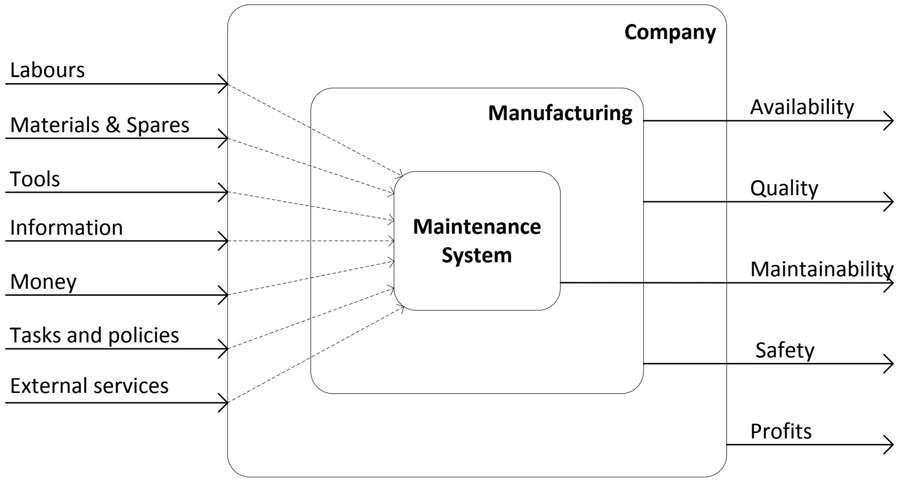


Figure 3-2 Input-output of maintenance within the company, adapted from Tsang (2002)

The integrated of these elements within the overall maintenance system produce the maintainability to directly support manufacturing function. It also contributes toward the equipment availability, product quality, and human safety in manufacturing performance. Overall, its performance influences profit as one of the company's achievements.

3.3 Business Perspective

To survive in the information age, the focus of the business is not merely converting raw material into high-value products, but also to manage intangible assets which influence the product acceptance such as customer relationship, employee skills, information and knowledge, and corporate culture (Kaplan and Norton, 2000). These intangible assets have a big impact in deciding whether such business can survive.

Business strategy as a derivation of business vision and mission is a starting point to generally define what the organisation will do against its competitors. It is a set of plan and policy required to identify its position whether it can either defend against competitive forces or influence them (Skinner, 1969; Porter, 1980). These objectives are translated into day-to-day operations to guide all organisation functions to head in the right direction. Therefore, the planned statements and policy guidance should be well-understood and be implemented operationally by each function in an organisation.

3.3.1 Business Strategy

Strategy can be simply said as all organized and systematic plans and actions to achieve the objectives. Mintzberg in the book of “The Strategy Process: Concepts, Contexts and Cases” (Mintzberg et al., 2003) basically divided strategy into five characteristics, as a plan, a ploy, a pattern, a position and a perspective. Business unit strategy is also called competitive strategy which focuses to create competitive advantage in a particular business unit (Porter, 1987). Furthermore, the business unit strategy should concern on identifying a market in which the company competes, and how to invest by considering the nature of competition (Hill and Hill, 2009).

Porter (1980) classified three generic business strategies which are cost leadership, differentiation, and focus. The matrix describing competitive advantage against competitive scope is shown in Figure 3-3.

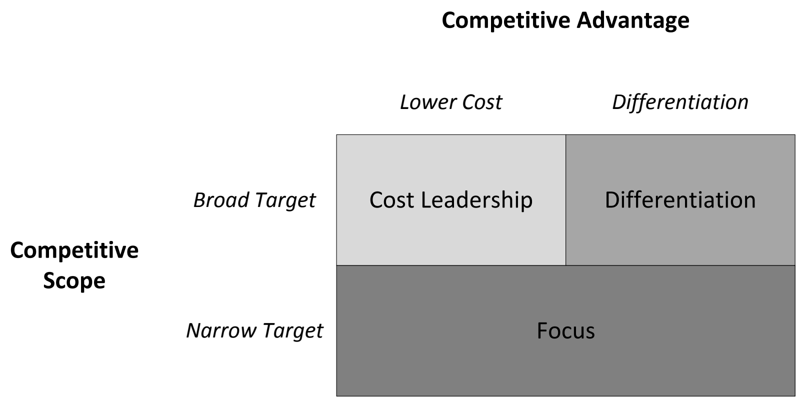


Figure 3-3 Three generic business strategy (Porter, 1980)

The cost leadership strategy put its main concern on tightening the cost and overhead control. It pursues to cover the broad target of the market. To achieve the low-cost product, the company usually give the intense supervision of labour, design the easily manufactured product, and implement low-cost distribution system (Porter, 1980). However, the lower cost should be equivalent to the created value compared with the competitors (Mathur and Kenyon, 2001). It means a slightly higher cost for a more attractive product is still considered as the cost leadership. Thus, it depends on how to gain customer attention on the value perception of the cost paid to create that value.

The opposite of cost leadership is the differentiation strategy. Although similarly pursuing to acquire broad target of the market, it focuses on the uniqueness of the product. Cost is not the primary concern, but it is maintained to meet the specified threshold. To succeed in this strategy, strong coordination among research and development, product development and marketing functions is required (Porter, 1980). It will be represented through high product innovation along with strong marketing abilities.

The third generic strategy is the focus strategy, afforded to fulfil the specified and customised product of the particular market. To meet its goal, this strategy combines those two strategies above in term of skills, resources, and organisation management.

Different from Porter who used competitive scope versus competitive advantage to identify business strategies, Kaplan and Norton (2000) classified three business strategies from the perspective of customer value; operational excellence, customer intimacy, and product leadership. Operational excellence ensures the customer to get the expected product and service, customer intimacy prioritises to fulfil the needs of a particular group of customers, and product leadership focuses on developing a breakthrough of product. Furthermore, they emphasised that no company will be able to provide the full range of products and services to all customer’s levels unless that unfocused strategy is replaced. The key point is that the company has to concentrate on one of the customer value propositions while keeping the other two are under threshold standards.

3.3.2 Translating Strategy into Measurable Performance through Balanced Scorecard

The achievement of strategy definitely cannot be measured from a single measurement perspective, such as from a financial perspective only. It also requires other measurement perspectives to provide a clear and balanced attention to the critical area of business strategy. Nonetheless, the overload information from a variety of perspectives might not be effective to represent the performance and may cause overlapping among performance criteria. For this reason, Balanced Scorecard (BSC) has received high attention in the last two decades and offers four perspectives which focus on the most critical factor on the organisation rooted from vision and strategy (Kaplan and Norton, 2005). It is claimed that BSC is able to clarify, communicate and manage strategy for both tangible and intangible assets as strategic measurement as well as strategic management system (Kaplan and Norton, 1996a). The overview of BSC with its four perspectives is presented in Figure 3-4.

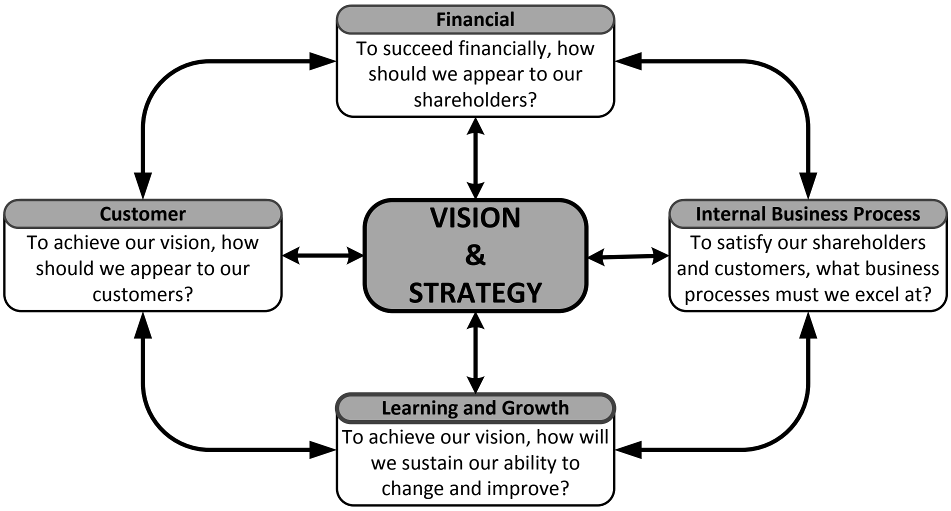


Figure 3-4 Translation of vision and strategy through four perspectives of BSC, adapted from Kaplan and Norton (2007)

Previously, financial perspective was used as the only one Key Performance Indicator (KPI) to assess company's performance. As it focused on short-term financial measures, it tended to inhibit the investment which had a long-term implication. To synchronise all above three perspectives of BSC with financial perspective in order to look forward to the future achievement, Shareholder Value Analysis (SVA) is considered to forecast future cash flows and then discount them back to a rough estimate of current value (Kaplan and Norton, 2005).

Customer perspective represents the commitment of company in delivering value to the customer. The core measures of customer perspective include customer satisfaction, customer retention, new customer acquisition, and customer profitability (Kaplan and Norton, 1996a). These measures are assessed through the combination of product and service attributes, customer relations, and corporate image offered by the company. Some categories used to represent customer's satisfaction are lead time, quality, product performance and service, after sale service, and cost.

To meet a customer's value proposition on the targeted financial objectives, the company must excel in its internal business process. It is focused on identifying and creating new processes that will give the greater impact on customer satisfaction (Kaplan and Norton, 1996a). It is represented by processes, decisions, and actions throughout the organisation (Kaplan and Norton, 2005). Some KPIs of the internal business process are the aspects that affect cycle time, quality, employee skills, productivity, and cost.

The point of learning and growth perspective is the continuity to innovate and improve the internal process and create value to gain customer's satisfaction through aligning human resources, system and organisation procedures with strategy. It is represented on the core competencies and skill, technologies, and corporate culture (Kaplan and Norton, 2000). The performance of this perspective can be represented by improvement of on-time delivery, cycle time, defect rate and yield (Kaplan and Norton, 2005).

Obviously, customer satisfaction is influenced by the performance of internal business processes. Improvement of process and value creation for the customer are continuously maintained through innovation and learning. Finally, those three perspectives are connected to each other to achieve expected financial performance. These interactions enable a company to monitor financial results by simultaneously controlling the development of capability and acquiring of intangible assets for the future growth (Kaplan and Norton, 2007).

Finally, BSC should be enacted as a template that might be customised regarding different characteristics and needs of the company. In this research, BSC will be employed to provide a guideline to translate company statement into required functional performances, in term of maintenance resources and maintenance rules required. Through its four-perspectives, the business strategies will be aligned to functional strategies and operational requirements to determine resources allocation and smooth the execution of maintenance activities.

3.4 Relationship of Business, Manufacturing, and Maintenance

The discussion about the contribution of maintenance to the business performance is very difficult to find in the early literature. Mostly, the business performance is connected with manufacturing performance, as mentioned by

Skinner (1969). He firmly argued that the mutual interrelation of business and manufacturing was more important than only concentrating on reducing production cost or increasing productivity. In fact, some industrial cases show that demand for high quality and unique products cannot be dealt with the economic sense of manufacturing process (Skinner, 1969). For instance, when a company states that it will compete in fulfiling the demand for a high quality and unique product, this should be complemented by a high level of the manufacturing process that impacts on increasing cost. Definitely, that is the way to be competitive and achieve profits. Therefore, all functions are dedicated to work synchronously in the same direction to reflect the insight of the company's vision. It is a kind of top-down disaggregation of business strategy into manufacturing strategy. This is more relevant to decide what performances a company needs from such function, instead of the bottom up approach which puts emphasis on high productivity and low cost on the first place, but then assumes what will be achieved by the company for its business. Thus the manufacturing strategy must be rooted in business strategy. Hence, as a competitive weapon, it should be able to accommodate market share in which a company aims to achieve.

On similar lines, Porter (1980) indicated that manufacturing is one of the business drivers to achieve a corporate goal, as depicted in Figure 3-5. There are ten drivers mentioned that proportionally contribute to the achievement of goals. But in that area, manufacturing is still considered individually, without realising the role of maintenance.

Playing a supporting function, maintenance cannot be separated from manufacturing. It is considered as a function of which its activities are carried out in parallel with manufacturing function (Duffuaa et al., 1999). As the implication of the dependency, the performance of maintenance relates to manufacturing performance, besides its own performance as an individual system. Furthermore, both of them are connected to achieve the business strategy as the way to gain competitive advantages.

Figure 3-5 The wheel of competitive strategy (Porter, 1980)

The concept of maintenance as a business driver started in the early 2000s. The survey conducted by Swanson (2001) confirmed the relationship between maintenance with manufacturing and business performance in term of product quality, equipment availability, and production cost. Meanwhile, another survey conducted by Pinjala et al (2006) showed that pro-active maintenance and better planning and control of manufacturing system are implemented by a quality business competitor. Gulati (2013) emphasized that implementation of best practice maintenance can improve performance, competitiveness and market share. Kaplan and Norton (2006) also noted the importance of strategic alignment among corporate, business units, functions, and external partners.

The company should design maintenance strategy based on manufacturing process characteristic to keep maintenance budget low, but manufacturing equipment retains on its best condition, and the manufacturing process can run on expected schedule and produce on quality tolerance. New maintenance paradigm is to learn the pattern of manufacturing process as well as manufacturing equipment specification to reach the best strategy of maintenance to work in. The relationship between organisation, manufacturing, and maintenance are presented in Figure 3-6.

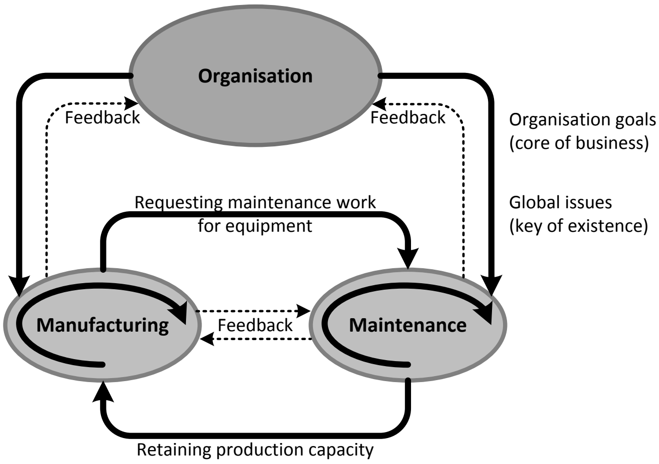


Figure 3-6 Relationship between organisation goal, manufacturing, and maintenance (Milana et al., 2014b)

There are three kinds of flows distributed to the maintenance system performance. The first flow describes the interaction of maintenance elements within maintenance system. This represents the movements of maintenance staffs, equipment and tools, spare parts, and information in completing maintenance tasks. The second flow moves information horizontally between maintenance and manufacturing function. By this, maintenance works based on manufacturing demand with respect to keeping manufacturing performance on the desired production capacity and quality (Gits, 1994). The third flow is linking maintenance vertically with corporate level. On this aspect, company environment and business orientation emphasise its commitments on quality, quantity, and delivery (Duffuaa et al., 1999) of product and service, particularly on maintenance perspective. Similarly, the global issues such as safety, social and environmental aspects are considered to be accommodated (Brown, 1996).

3.5 Chapter Summary

The role of strategy and operations in a particular function cannot be separated. The strategy is arranged to be a driving force to play a day-to-day operation. To develop a proper maintenance strategy and operations, it is required to know what elements are involved. These could be classified into structural elements as the tangible resources of maintenance and infrastructure elements such as the methods, tasks, and policies of maintenance. The understanding of the roles of these elements will ease in improving it as parts of maintenance system. The direct output of a proper maintenance strategy and operations can be seen on the maintainability of manufacturing equipment. It also gives the indirect impact on quality, safety, and availability of the manufacturing process, and influence the financial achievement of the company.

Integrated maintenance strategy and operations require the integrative decision pattern of different elements from maintenance itself, manufacturing and business perspectives. Business strategy as a derivation of business vision and mission is a starting point to generally define what the organisation will do against its competitors. It indicates the measurable plans, actions, and targets of the vision and mission statement. Generally, there are three types of business strategy, which are cost leadership, differentiation, and focus. Each type has different characteristics and approaches to gain its objectives. However, generating business strategy is not enough to obtain an appropriate implementation. The strategy has to be translated into measurable performance.

The achievement of strategy cannot be measured from a single measurement perspective but must encompass other perspectives to provide a balance attention with respect to long-term achievement. For this need, Balance Scorecard appears as the solution to identify, measure, and manage strategy from both tangible and intangible assets in four perspectives. Those are financial, customer, internal business process, and learning and growth. They represent overall considerable factors in balance within a company in order to achieve its vision and mission. With the guideline of BSC, a business strategy can be translated into operational action on each function.

The translation process of strategy into operational action is also helpful to connect business level with the lower functional level. On this matter, maintenance function could clearly show its relation to manufacturing and business. Since the role of maintenance in manufacturing performance and business competitiveness has been discussed, the interaction patterns among them can be clearly identified.

The integration of maintenance with business and manufacturing perspective in this research is supported by a hybrid KB system. Therefore, Chapter 4 discusses the methodology used, which is the combination of KB System, GAP, and AHP analysis.

CHAPTER 4

Knowledge-Based System, Gauging Absences Pre-requisites and Analytic Hierarchy Process

4.1 Introduction

People need intelligence to acquire knowledge so that it can be deployed to solve a problem. One of the big issues in this digital era is creating a computerised technique to imitate the human intelligence to enable the computer solving the problem as the human being. The popular term used for this is Artificial Intelligence (AI). This chapter initially presents the relationship between data, information, knowledge, and wisdom. Then AI and some applications of AI are discussed to give the overview about the current emerging field of AI to support decision making, with a particular discussion on the KB System. As this KBIMSO framework integrates GAP and AHP in the KB systems, the discussion about GAP and AHP are also presented at the end of the chapter.

4.2 Knowledge

Knowledge is commonly discussed in term of how it is developed and shared. The potential capability to act by acquiring knowledge distinguishes it from information and data. But, higher than knowledge, there is a wisdom that enables people to employ knowledge in a beneficial way (Giarratano and Riley, 2005). To show how knowledge is positioned among data, information and wisdom, the discussion about knowledge hierarchy is presented. Meanwhile, to understand how the knowledge can be shared, transferred, and transformed, the knowledge conversion process is also highlighted.

4.2.1 Knowledge Hierarchy

The discussion about knowledge will bring some repeated terms such as data, information, knowledge, and wisdom. They are known to have high relationship each other. Their relationship is figured out in a hierarchy as depicted in Figure 4-1.

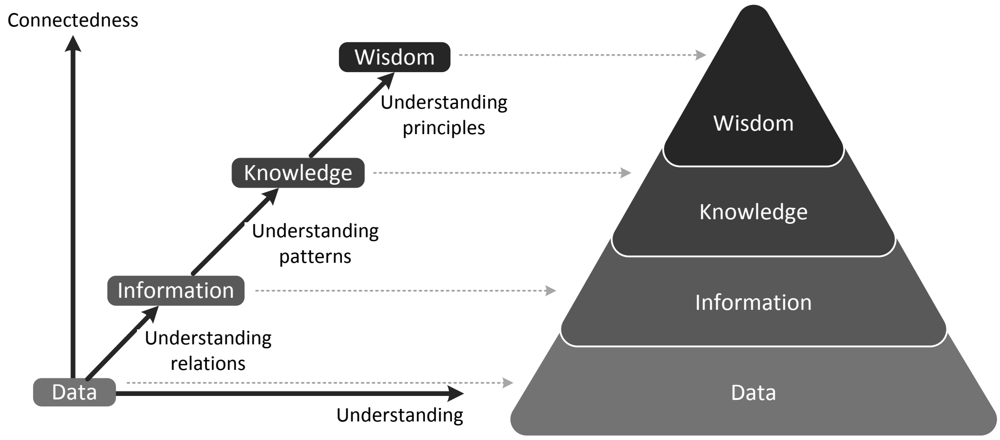


Figure 4-1 The relationship from data to wisdom (Cooper, 2010)

Data can be defined as the meaningless fact (Braganza, 2004; Elgh, 2008) or the discrete value (Cooper, 2010). It is recorded by numbers, letters or certain features (Du, 2010) without regarding context or usability. Examples of data are the name of equipment, the name of the city, type of occupation, etc.

By arranging data in a particular context and purpose, information is generated. Hicks et al (2006) defined information as the meaningful data that has been analysed and interpreted. In addition, Frappaolo (2002) argued that information is the structured data without generating action. It can be seen from the correlation that shows the relation between two or more variables, for instances, the relation between a number of employees and size of the company, product quality, and customer satisfaction, or equipment reliability and delivery time. Furthermore, Joseph and Mark (2005) claimed that information is the result of interaction within a particular environment. It is used as input to create knowledge for making a decision (Pomerol and Brézillon, 2001).

Continuing the concept of “information is the meaningful data”, knowledge is defined as the meaningful information (Jean-Baptiste et al., 2008). On a slightly different perspective, Stacey (2001) argued that knowledge is the process itself instead of the result of information process. This argument is understandable as once the knowledge produced and documented, it will be stored as the information. Thus, knowledge can be seen as the active process rather than the lagging result of information process.

On developing knowledge, information is processed by synchronising of data, personal context, belief, and experience. It is typically presented as an action after connecting some multiple experiences and perspectives in a particular environment (Frappaolo, 2002). For example, the integrated information of product demand, bill of material, available inventory (in term of raw material, work in process and finished goods inventory), and lead time for each part to be ready for assembly, will lead a knowledge of how many part required to be purchased or produced, and when to purchase or produce it. Through this example, the obvious difference between information and knowledge are achieved. Information presents structured relevant data, and then knowledge processes them to generate an action. Finally, it can be concluded that knowledge is an advanced integration and interpretation of information in particular context and field that is accompanied by action.

Another term used in discussing knowledge is wisdom. Although less popular than the other three terms above, wisdom lies on the top level of knowledge hierarchy, as can be seen in Figure 4-1. Cooper (2010) described it as an extrapolative process of knowledge assimilation which involves moral and ethical edge. It enables one to process and create knowledge in some meaningful ways (Jean-Baptiste et al., 2008). Milana (2011) concluded that wisdom is a light of insight that appears through the integration of knowledge with experience and know-how. On this level, data and information are not always required as it embodies the knowledge principles in the advanced pattern. Advanced connectedness of contextual facts combined with an advanced understanding of the patterns leads to a wisdom that enables people to get insight into acquiring creation and innovation.

4.2.2 Knowledge Conversion

Knowledge conversion cannot be discussed without initially identifying types of knowledge. Knowledge is distinguished into explicit knowledge and tacit knowledge. Explicit knowledge is an easy-transferable knowledge. It is structured, externalised and can be shared and captured through information technology device (Martensson, 2000). It can be transferred into information that can be documented, stored and retrieved by others to create their own knowledge.

Tacit knowledge is also called unconscious knowledge for its inability to be exposed by language (Giarratano and Riley, 2005). It is retained in human minds, experience, and behaviour which grow through developing skill and practice (Martensson, 2000). It is difficult to be externalised, shared and captured precisely.

Although many scholars argue that tacit knowledge cannot be peeled off from human beings and can be shown from how they act and make decisions, some others are firmly sure that tacit knowledge is transferable and can be transformed into explicit knowledge. Those who stand on this argument claim that tacit knowledge could be converted into explicit knowledge (Nonaka and Takeuchi, 1995), as depicted in Figure 4-2.

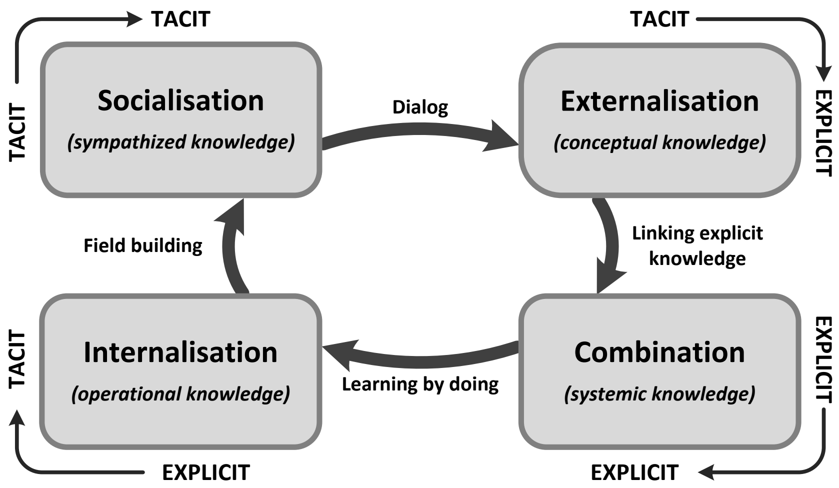


Figure 4-2 Knowledge conversion (Nonaka and Takeuchi, 1995)

Socialisation is the way to develop the relationship amongst people. It could be a gathering event, in a formal as well as in an informal forum. It might share tacit knowledge from a person to others in the form of sharing opinion, idea, or experience. The tacit knowledge received will still remain tacit, as it has no structure yet. When a person implements such knowledge in completing his task and then documents it, the implemented knowledge is no longer the same. Through involving the personal skill, experience, and culture, a new knowledge is created, externalised and transformed into explicit knowledge. By combining such explicit knowledge with other existing knowledge in an organisation, the new knowledge will be created to solve many different problems. The routine employment of such knowledge could improve the skill and know-how which could be internalised into tacit knowledge and become an individual property that will remain in human mind.

4.3 Artificial Intelligence

The earliest pioneer in machine intelligence is Alan Turing, a mathematician and computer scientist, who queried whether the computer could think as human through his experiment called the Turing Test. He then wrote the most significant paper of “Computing Machinery and Intelligence” in 1950 (Negnevitsky, 2011). The term of Artificial Intelligence (AI) was introduced by John McCarthy in the 1950s in which Allen Newell, Herbert Simon, and J. C. Shaw introduced “Logic Theorist” which is recognised as the first AI program (Awad, 1996; Jones, 2008). Afterwards, the research on AI grew rapidly in many different fields.

4.3.1 From Intelligence to Artificial Intelligence

Intelligence is the ability to acquire and apply knowledge and skills (Oxford Dictionary, 2014). Jones (2008) defined it as a set of properties of the mind which enable it to make a right decision by being given a set of inputs and possible actions. When the human intelligence is imitated and their way of thinking is copied into a computer to enable it doing a cognitive task, it is called Artificial Intelligence (AI). Awad (1996) and Munakata (2008) similarly defined AI as the science of making computers do things that the human needs intelligence to do. But that is not the only way to define AI. Russell and Norvig (2010) summarised that AI can be defined from four different perspectives, acting humanly, thinking humanly, thinking rationally, and acting rationally.

The term of AI is commonly used in the computing science. The aim is to simulate the computer to work as human being to solve the problem. A simple hint to recognise AI is when a set of procedures enable a computer to see, hear, understand, and develop reasons to create a similar result as a human does, it can be called AI (Awad, 1996).

4.3.2 The Applications of Artificial Intelligence

The application of AI is widely ranging on different format and techniques to meet different requirement. Some of AI techniques which are widely used will be discussed in the following sections. These are Artificial Neural Network, Case-

Based Reasoning, Genetic Algorithm, Fuzzy System, and Expert System/Knowledge-Based System.

4.3.2.1 Artificial Neural Network

A neural network is a modelled system of processing elements of the human brain's network called neurons (Awad, 1996). Since this method imitates the biological neuron process in the human brain, it is called Artificial Neural Network (ANN). ANN is intended to solve an interesting but cumbersome problem that cannot be carried on by traditional computer programme through mimicking networks as neurons and connecting them (Jones, 2008). The typical architecture of ANN is shown in Figure 4-3. The application of ANN has been attempted in the area of risk management, credit card fraud detection, check and signature verification, and mortgage appraisals (Awad, 1996).

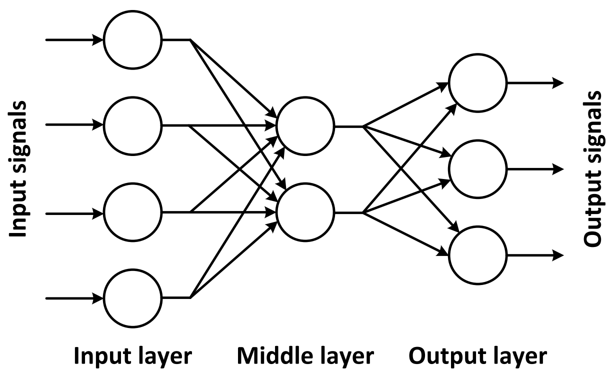


Figure 4-3 Architecture of typical Artificial Neural Network (Negnevitsky, 2011)

Each neuron is connected through links which have a numerical weight, also known as a long-term memory in ANN (Negnevitsky, 2011). Those neurons are arranged in the network along the layers. Input layers receive input signals from the outside and pass it to middle layers. The input signal could be in the form of raw data or output from other neurons. Middle layers then identify the features through the weight of input signals. The features are then translated into the pattern and sent to output layers. The output signals could be used as the final result or as the input for other neurons.

The transfer process, a so-called *activation function*, to weight the input signal, X, and compare it with a threshold value, θ, follows the equations below (Negnevitsky, 2011):

$$X = \sum_{i=1}^{n} x_i w_i \qquad \text{Equation (1)}$$

$$Y = \begin{cases} +1 & if\ X \geq \theta \\ -1 & if\ X < \theta \end{cases} \qquad \text{Equation (2)}$$

where X is the net weighted input to the neuron, x_i is the value of input i, w_i is the weight of input i, n is the number of the neuron inputs, and Y is the output of the neuron. This type of activation function is called a sign function. Thus the actual output of the neuron with a sign activation function can be represented as:

$$Y = sign[\sum_{i=1}^{n} x_i w_i - \theta] \qquad \text{Equation (3)}$$

The ANN learning algorithms could be differentiated into two categories; supervised learning and unsupervised learning (Jones, 2008). Supervised learning algorithms train ANN to identify the right and wrong answers, find the error and adjust the weight, whereas the unsupervised learning algorithms do not guide the ANN to provide the specified answer (Mohamed, 2012). It is merely used to find the similarities and the differences among data and show the relationship of them.

4.3.2.2 Case-Based Reasoning

The essence of Case-Based Reasoning (CBR) is to recall the previous experience when the similar case arises (Hopgood, 2001). By this approach, CBR uses an existing database of old problem solution to address the problem on the new situation (Luger, 2009). This method is working properly for an expert who has experienced on a particular domain. Those experiences help him to reuse the reasoning of cases from the past to overcome the current problem (Awad, 1996). The solution sources to sort out the current problem could be generated from knowledge of engineering process or the previous result of problem-solving (Luger, 2009) by following a methodology as shown in Figure 4-4. CBR is widely used in fault diagnosis, engineering sales, help-desk support, and planning (Hopgood, 2001).

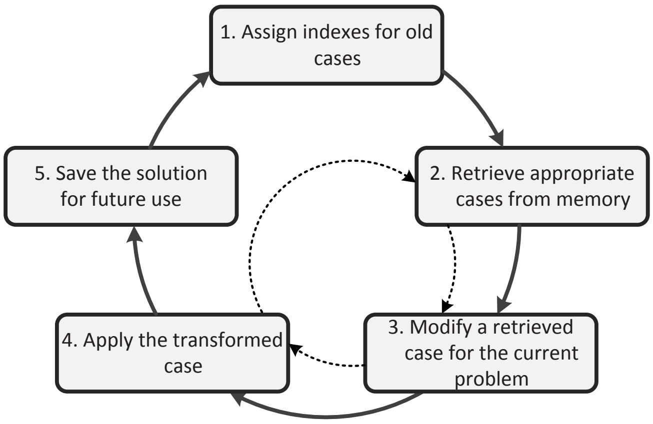


Figure 4-4 Methodology of Case-Based Reasoning, adapted from (Turban et al., 2007) and Luger (2009)

The old cases are indexed to help identify similarity of case features. The search engine tool in CBR system retrieves the appropriate cases heuristically from the *case-base*. It identifies the similar cases based on interpretation of both human and reasoning tool by referring to particular features. The CBR system then relates the old cases with the current problem and modifies those old cases based on current situation. The transformed case and modification solution are then applied to the current problem with a further iteration of "retrieve – modify – apply". Finally, the implementation is documented and stored in the *case-base*, regardless of whether it a success or failure, as references for the future similar problems.

4.3.2.3 Genetic Algorithm

This type of AI is the population-based algorithm which is inspired by the biological process of evolution (Turban et al., 2007). Each cell of an individual organism contains chromosomes as the determinant of creature's characteristics. A chromosome is made up of genes for which it determines a specific feature (Hopgood, 2001). The level of fitness of chromosome influences its chance to reproduce and pass its characteristics to the next generation.

In Genetic Algorithm (GA), chromosomes are known as the population of the candidate solution. Genes are represented as bit-strings of a binary number, one and zero (Negnevitsky, 2011). To find the solution space, GA uses the crossover, mutation, and inversion of evolutionary programming (Hopgood, 2001; Jones, 2008), as illustrated in Figure 4-5. Meanwhile, the basic steps of GA are shown in Figure 4-6.

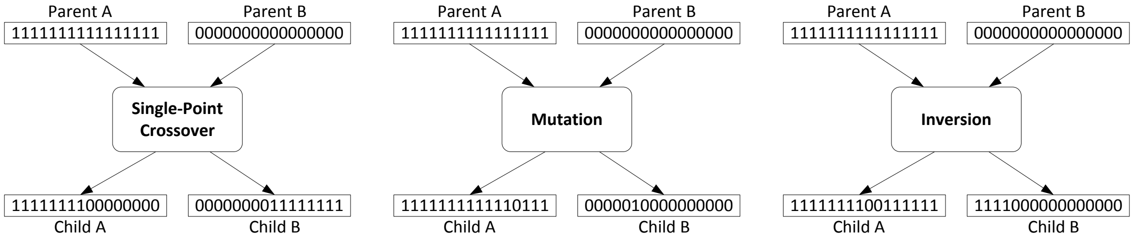


Figure 4-5 Illustration of crossover, mutation, and inversion in GA (Jones, 2008)

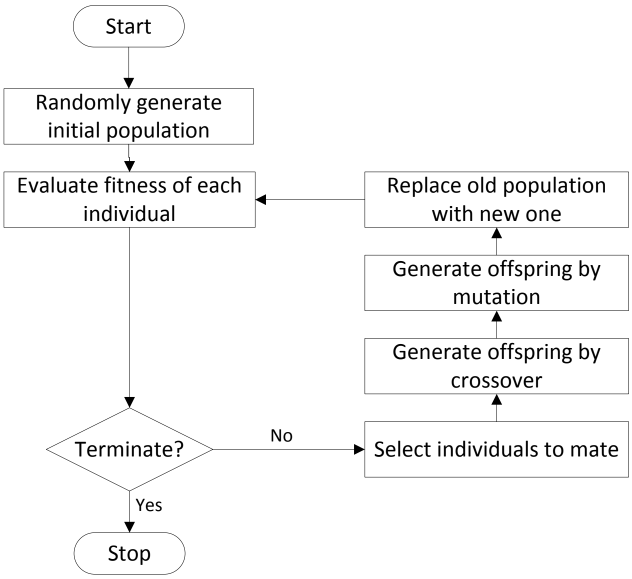


Figure 4-6 Basic steps of Genetic Algorithm, adapted from Hopgood (2001)

Initialisation of the population as a set of solution is generated randomly where an individual's chromosome is evaluated based on the fitness function (Munakata, 2008). The fitter individual is more likely to be selected instead of the unfit ones. Reproduction of next generation is generated through crossover or recombination breeding between pairs of chromosomes and then applying mutation of the chromosome to each offspring. These iteration processes will be repeated until the best solution is achieved among them.

Furthermore, this method is followed by the development of Generic Programming and Evolutionary Strategies which replace the use of bit-strings as the genetic algorithm with other methods. Whilst Generic Programming uses Sexpressions or program trees as the encoding system, Evolutionary Strategies focuses on optimisation of real value parameters (Jones, 2008).

4.3.2.4 Fuzzy System

Fuzzy System (FS) deals with fuzzy logic which is related to the ambiguity, lack of definition and inexact knowledge with approximate rather than the exact logic of reasoning (Awad, 1996). It means that FS manages unclear boundaries on the particular problem by using the common-sense rules with uncertain data and infinite quantity. In a different way, Negnevitsky (2011) explained that FS represents the way of people think by modelling the sense of words, decision making, and common sense. Fuzzy logic uses the mathematical theory of fuzzy sets to allow the computer to behave less precisely and logically by considering not only right or wrong but also the “grey” area on the middle of them (Liao, 2005; Turban et al., 2007). For this reason, a fuzzy system is suitable to be applied when the conventional approach cannot provide the desired result and mathematical approach is hard to derive. It is usually used in the fuzzy control of physical and chemical characteristics, such as the motion of the machine, the flow of liquid or gas, and temperature (Munakata, 2008).

In the non-fuzzy set, the membership of element – called crisps, is only separated into two degrees, belongs to (1) and does not belong to the set (0) (Munakata, 2008), while in the fuzzy set, the crisps also contain some degrees between 1 and 0. The case example of “tall man” can be used to represent the fuzzy set. The crisps consist of three sets; short (150 – 170 cm), average (170 – 180 cm), and tall (> 180 cm), as illustrated in Figure 4-7a. If the boundary is set firmly, a 179 cm tall man is classified as the member of the average group, but a 181 cm tall man is classified as the member of the tall group. This distinction is not acceptable in common sense because this small difference of tall could significantly influence further treatment for him at the different group (Hopgood, 2001).

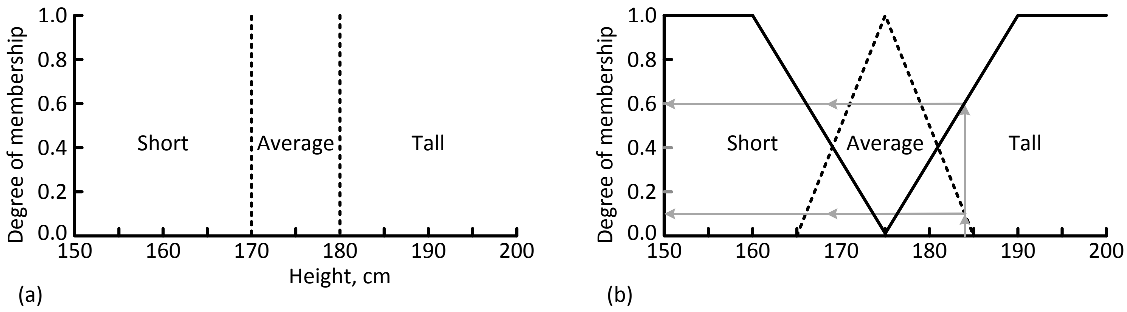


Figure 4-7 Illustration of crisp set (a) and fuzzy set (b) (Negnevitsky, 2011)

By referring again to Figure 4-7, a 184cm tall man is not only to be classified as a member of the tall group. Instead, he is part of both average and tall groups but at different degree, as illustrated in Figure 4-7b. A 184 cm tall man is considered as a member of the average group with a degree of 0.1. At the same time, he is also part of a tall group with a degree of 0.6. By this, it means that he has partial membership in multiple sets (Negnevitsky, 2011).

4.3.2.5 Expert System/Knowledge-Based System

Expert System (ES) as an application of AI works intelligently as a human being in recommending advises of input problem (Liao, 2005). However, it is also known as part of Knowledge Management (KM) which involve all knowledge assets in its design (Becerra-Fernandez et al., 2004). ES is intended to act as an expert to consult a range problem in a particular and narrow area of expertise to create a solution (Hopgood, 2001). Therefore, the solution created should be complemented with the logic and reason to reach the conclusion. The conclusion produced is commonly called inference. By combining knowledge and inference, it is focusing on problem-solving by assisting the thinking process instead of merely providing information (Awad, 1996; Giarratano and Riley, 2005). When the knowledge is represented through generated and structured rules, inference represents the product of those rules to be gained by applying the ES.

The term of Expert System (ES) and Knowledge-Based (KB) System are used synonymously. On its development, the experts realised that even the most advanced expert system cannot beat the expert in dealing with given problems. Although ES could be powerful to gain a solution problem, it is only capable to face an individual case. To deal with another case, ES should be developed again from the beginning. The “brain” of ES is developed through the systematic algorithm of information and knowledge acquired by an expert. Considering that the Expert System is not truly capable of making a human expert as it is supposed to be, the term of ES is often replaced with Knowledge-Based System. Therefore in this research, the use of ES is presented as the KB System. As the method used in this research, the discussion about KB System in order to support the IMSO is detailed in the following sections.

4.4 Structure of Knowledge-Based System

As a branch of Artificial Intelligence, Knowledge-Based Systems have a better capability to provide a flexible meaning than conventional methods to gain the solution of a variety of problems (Liao, 2005). A KB System emphasizes its purpose to assist a person's thinking process on the problem solving (Awad, 1996). But, instead of merely doing numeric computation, a KB System provides some logical reasons under its recommendation by employing stored information within its databases through embedded rule-based systems. Therefore, the solution proposed by a KB system should be as valid as the solution from a domain expert (Ammar-Khodja et al., 2008). The structure of rule-based systems within a KB System is illustrated in Figure 4-8.

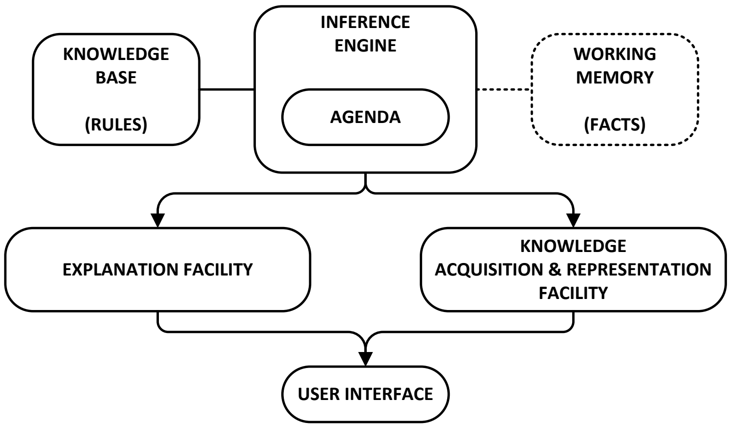


Figure 4-8 Structure of a Knowledge-Based System, adapted from Giarratano and Riley (2005)

Similar with the above structure proposed by Giarratano and Riley (2005), Hopgood (2001) also noted the similar key elements of KB System, which are knowledge acquisition, knowledge base, explanation facility, inference engine and interface modules. In summary, the architecture of a KB System consists of three main elements namely knowledge base, knowledge acquisition and representation, and inference engine. In practice, some other elements are required to enable its operation. The explanations of the main elements of a KB System are presented below.

4.4.1 Knowledge Base

A knowledge base consists of facts and rules. Facts might include sequences, structured entities, attributes of entities, and the relationship between them which are assumed to be correct at the time when they are used (Hopgood, 2001). 'Fact' is also defined as the general statement which refers to either temporary or permanent knowledge (Mohamed, 2012). Meanwhile, 'rule' (also known as production rule) is a method to represent knowledge by using facts. A global database of facts is used in rules as the knowledge base (Giarratano and Riley, 2005). In the KBS/ES, facts as the problem-specific information are stored in the database, while production rules as the expressed knowledge are stored in knowledge-base (Negnevitsky, 2011). Both of them will be used for the Inference Engine.

Expressing facts in rules could be done in a simple way. Production rules consist of two parts; antecedent which uses IF statements and consequent which uses THEN statement (Negnevitsky, 2011), in the form of:

$$\textbf{IF}\ \underbrace{\textit{<premise/condition>}}_{\text{antecedent}}\ \textbf{THEN}\ \underbrace{\textit{<conclusion/action>}}_{\text{consequent}}$$

with an example:

IF the red light is triggered **THEN** the machine is stopped

In a more complex condition, where there are more than one premises or conclusions, the production rules will be complemented with AND and OR statements, in the form of:

IF <premise/condition> **AND** <premise/condition> **THEN** <conclusion/action> **OR** <alternative>

with an example:

IF *the manufacturing team involved in deciding the manufacturing process flow*
AND *the engineering team involved in deciding the manufacturing process flow*
AND *the maintenance team involved in deciding the manufacturing process flow*
AND *the quality team involved in deciding the manufacturing process flow*

AND *the product development team involved in deciding the manufacturing process flow*
AND *the marketing team involved in deciding the manufacturing process flow*
AND *the manufacturing process flow considering the aspect of cost*
AND *the manufacturing process flow considering the aspect of safety*
AND *the manufacturing process flow considering the aspect of maintenance*
THEN *the manufacturing process chosen is good and considering multifunctional requirements*
OR *the manufacturing process chosen is poor and fragmented without considering multifunctional requirements*

Rules should be clear, expressive and straightforward (Hopgood, 2001). To apply rules, a system requires access to facts that could be derived from database, connected sensor, or interactive user.

4.4.2 Knowledge Acquisition and Representation

Knowledge acquisition consists of eliciting, analysing and interpreting the knowledge from the human expert (Awad, 1996). The expert for this needs are either knowledgeable people conceptually, or the experienced user practically. The techniques applied for acquiring knowledge could be through discussion, direct interviews or indirect questionnaire. The communication with experts will be used to develop a knowledge base while input from experienced user intended to ensure that the system is developed as intended.

Knowledge representation aims to ease computer in reasoning and understanding the relationship between elements of the knowledge base (Jones, 2008). Due to its contribution to solving the problem, the way to store knowledge is the important part of knowledge representation. It enables storing knowledge into the system automatically by the user without explicitly coding the knowledge (Giarratano and Riley, 2005). It does not only locate knowledge in a structural manner in knowledge directory but also be able to process acquired knowledge to generate reason as the basis for decision making. There are some mechanisms used for knowledge representation, such as semantic networks, frames, proportional logic and first-order (predicate) logic (Jones, 2008). The first two are used to merely store knowledge on a proper way to represent knowledge, while the latter two are intended to process knowledge as well.

4.4.3 Inference Engine

Inference engine works to make inferences through linking rules with suitable facts, prioritise the satisfied rules and execute rules based on priority (Giarratano and Riley, 2005). Simply, it is a tool to determine which rules to apply and when to apply them (Hopgood, 2001). The famous methods which are used frequently are forward chaining and back chaining. The explanations about those two methods are discussed in much more detail in the following section.

4.4.3.1 Forward Chaining

Forward chaining, also called data-driven, is usually used for the problem of interpretation to find out whether the system can inform about some particular data (Hopgood, 2001). It is used to generate the solution by adding a new fact to the system (Russell and Norvig, 1995). Then the selected rules are applied regarding the current *fact-based* of which it is comprised of all facts derived from rules or direct supplies and stored in the system (Hopgood, 2001).

According to Hopgood (2001), forward chaining as a data-driven approach is started by examining all rules from *fact-based* without corresponding to the predetermined goal. It means that data is considered as much as possible while the output is unpredictable. All satisfied rules are then triggered which lead to making up a conflict set among some rules. As only one rule could be fired, a conflict resolution approach is required to select a satisfied rule in such given cycle. The illustration of forward chaining is presented in Figure 4-9.

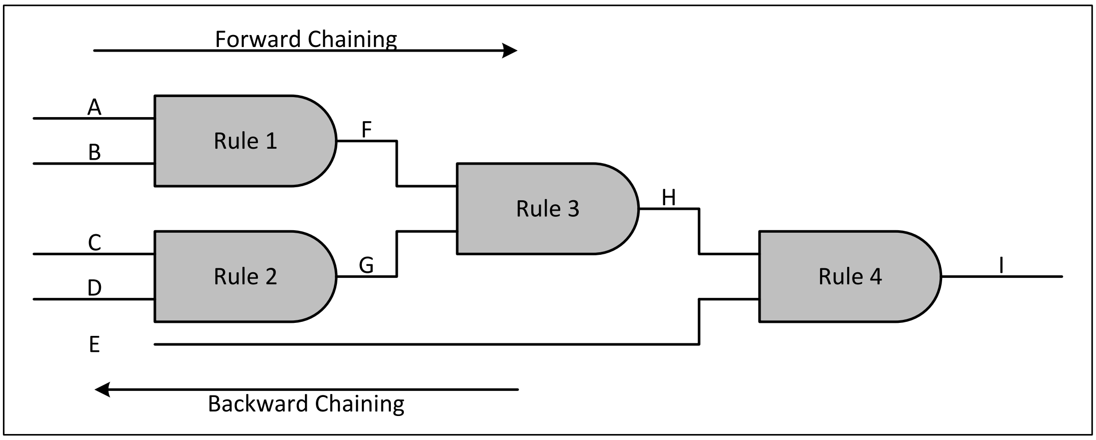


Figure 4-9 Forward and Backward Chaining approach (Mohamed, 2012)

By symbolising the initial facts as A, B, C, D, and E, so the production rules are as the following:

IF A **AND** B **THEN** F
IF C **AND** D **THEN** G
IF F **AND** G **THEN** H
IF E **AND** H **THEN** I

The initial known facts A and B direct us to conclude F through Rule 1, so F is now a known fact. We also have initially known facts C and D which direct us to conclude G through Rule 2, so G is now another known facts. Through the known facts F and G, we can conclude H through Rule 3. Since we now know H and already know E at the beginning, we can conclude I through Rule 4. Since I is the solution, the forward chaining will stop here.

4.4.3.2 Backward Chaining

Backward chaining or goal-driven works backward by considering the solution of given problem and establishing the premises of the implications to reach such solution (Russell and Norvig, 2010). It chooses to specify the goal as the initial step to solve the problem. As it is intended to find the focused solution, only those rules which contribute to the achievement of goal will be selected and examined (Hopgood, 2001).

When some particular rules are selected to reach the goal, the conditions to support those rules are required. Thus those rules become the new sub-goals which also need some supporting rules to fulfil their condition. This backward chaining process continues until it works back to the fact of the problem (Luger, 2009). The illustration of backward chaining is also presented in Figure 4-9.

By using the similar symbol as in the forward chaining illustration, I is defined as the conclusion. To achieve this conclusion, we need to know facts H and E through Rule 4. E is already known as initial facts. To know H, we need to know facts F and G through Rule 3. To know F, we need to know facts A and B through Rule 1, while to know G, we need to know facts C and D through Rule 2. Next, we find that A, B, C, and D are the initial facts. Since all initial facts already found, we can verify that I can be concluded by finding facts and rules through backward chaining.

4.5 Gauging Absences of Pre-requisites

The development of KBIMSO requires a benchmarking technique to compare the existing system and its desired position. It is intended to encourage continuous learning (Mohamed, 2012; Nawawi, 2009; Udin, 2004; Wibisono, 2003) and identify the potential improvement by finding and fulfilling the gap between them. For this benchmarking purpose, the Gauging Absences of Pre-requisites (GAP) is embedded into the Knowledge-Based System (Khan and Hafiz, 1999; Udin et al., 2006b).

GAP is a benchmarking technique used to identify and assess the gap between a pre-requisite state and an existing state in a particular system (Nawawi et al., 2008). Benchmarking can be conducted through internal and external perspectives. Internal benchmarking is comparing existing condition with the best previous performance, prospective target, or technical standard (Wibisono, 2003). Meanwhile external benchmarking is reflecting the best practices of other departments, business units, and competitors from a similar industry to identify the competitive position and find the creative ideas for continuous improvement. Mohamed (2012) noted that there are at least three targeted objectives in implementing GAP. Those are identifying the main requirement of the system, comparing current system status against the benchmark standards, and identifying the strength and weakness of current system against the proposed new system. The details about generated levels of GAP analysis and its integration into the KBIMSO are discussed in Section 5.9.2.

4.6 Analytic Hierarchy Process

Facing the formulation of an integrated maintenance strategy and operations which consists of various elements to be considered, Analytic Hierarchy Process (AHP) appears as the appropriate method to deal with this complexity. AHP approach has been used as a multi-criteria decision making technique. It could deal with unstructured and complex considerations such as tangible and intangible, financial and nonfinancial, as well as quality and quantity, simultaneously (Razmi et al., 1998; Saaty, 2008; Oeltjenbruns et al., 1995).

The applications of AHP has been used widely to overcome the problems of selection, evaluation, benefit-cost analysis, allocations, planning and development, priority and ranking, and decision making (Vaidya and Kumar, 2006). Although initially it is just used as a single technique of decision making, it is recently often modified such as in the form of fuzzy AHP (Chan and Kumar, 2007), or combined with other techniques such as ANN (Kuo et al., 2002), Quality Function Deployment (Chen et al., 2007) and goal programming (Bertolini and Bevilacqua, 2006), to name but a few.

In the area of maintenance, AHP also has been used to solve many issues. Labib et al (1998) deployed AHP to prioritise different criteria to sort machines according to criticality. Bevilacqua and Braglia (2000) used AHP to select the appropriate maintenance strategy for different facilities in an oil refinery company. For a similar aim, Wang et al (2007) used a fuzzy AHP, which is a modified AHP, to evaluate maintenance strategies for different equipment as they argue that mixing maintenance strategy may increase availability and reliability of equipment without a great increase of investment. Since AHP is a flexible combined method, Arunraj and Maiti (2010) incorporated it with goal programming to select an appropriate maintenance policy based on the risk of failure and cost of maintenance. For similar reasons, Ilangkumaran and Kumanan (2009) proposed criteria of environmental conditions, component failure, training, and flexibility to decide the best maintenance policy by combining AHP and Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS).

AHP performs through breaking down a complex situation into component parts, arranging them into a hierarchical order and weight them with numerical value based on user judgement to determine the overall priorities of the variables (Labib et al., 1998). It can confirm correctness and integrity of the comparison (Khan and Wibisono, 2008; Mohamed and Khan, 2012; Nawawi et al., 2008; Udin et al., 2006b) to keep the consistency on the iterative process. The mechanism of AHP is illustrated in Figure 4-10. Meanwhile, the structured hierarchy is shown in Figure 4-11

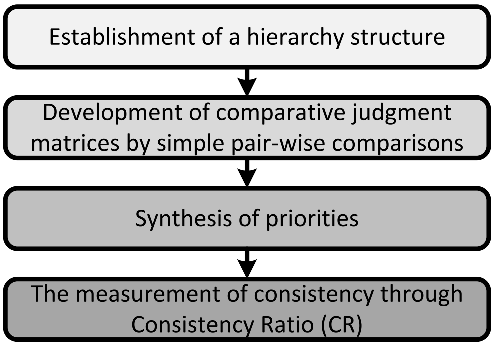


Figure 4-10 The mechanism of Analytic Hierarchy Process, adapted from Ilangkumaran and Kumanan (2009)

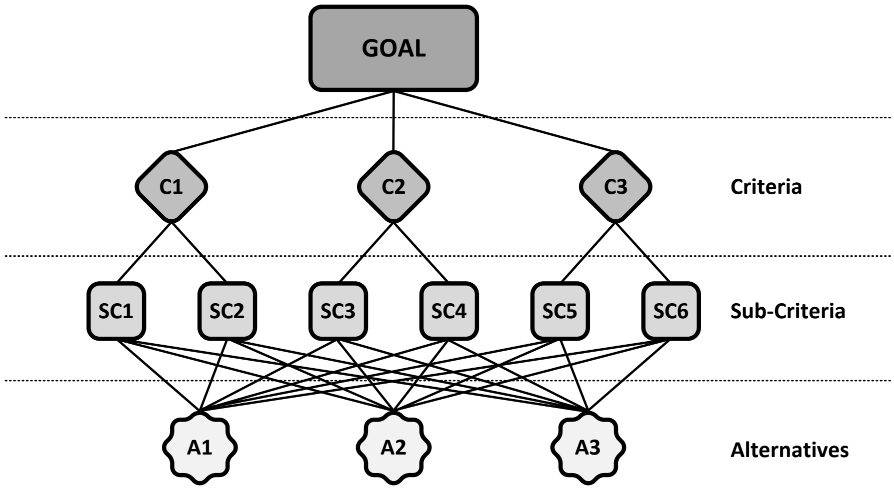


Figure 4-11 The hierarchy level of AHP (Saaty and Vargas, 2001)

The top level of the hierarchy, called goal, only consists of one element as a statement of decision making objective. The second level is positioned by criteria and sub-criteria that affect goal. Each criterion is mutually exclusive and their priority does not depend on its subsequent level. The lowest level of the hierarchy is referred to as decision alternatives (Razmi et al., 1998; Ilangkumaran and Kumanan, 2009).

The process is continued by comparing criteria with a pair-wise comparison, as shown in Figure 4-12. In this step, the first criterion on the AHP hierarchy is compared with the other criteria. The pair-wise comparison is repeated until the last criterion is compared to others.

	C1	C2	C3
C1	1	C1/C2	C1/C3
C2	C2/C1	1	C2/C3
C3	C3/C1	C3/C2	1

Figure 4-12 Matrix for Pair-Wise Comparison

The weight of each criterion represents the level of importance of them with respect to the aim of decision making. As the guidance, the AHP provides the fundamental scale showing the intensity of importance of criterion when it is compared to others as can be seen in Table 4-1. The less important criterion to the goal is represented at Level 1 in the intensity of importance. The intensity is increased into Level 9 which shows the most important of such criterion toward the goal. The even numbers represent the intermediate value between its upper and lower level.

Table 4-1 The fundamental scale of AHP (Saaty, 1990)

Intensity of Importance	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective
2	Weak	
3	Moderate importance	Experience and judgement slightly favour one activity over another
4	Moderate plus	
5	Strong importance	Experience and judgement strongly favour one activity over another
6	Strong plus	
7	Very strong or demonstrated importance	An activity is favoured very strongly over another; its dominance is demonstrated in practice
8	Very, very strong	
9	Extreme importance	The evidence favouring one activity over another is of the highest possible order of affirmation

Wang et al (2007) listed some advantages of AHP as the following:

a. It is one of the most known multi-criteria decision making models that can measure the consistency in the decision makers' judgements.

b. It can help the decision makers to organize the critical aspects of a problem into a hierarchical structure similar to a family tree, making decision process easy to handle.
c. Pair-wise comparisons in AHP are often preferred by the decision makers, allowing them to determine weights of criteria and scores of alternatives from comparison matrices rather than quantify weights/scores directly.

Considering the subjectivity and dynamic changes of decision maker on assessing each criterion against others on the pair-wise manner, the inconsistency of comparison is likely to appear (Aguilar-Lasserrea et al., 2009). As a 100% consistency might not be guaranteed, the consistency ratio is employed with inconsistency allowance of maximum 10%. The further details about the implementation of AHP along with its integration into the KBIMSO are discussed in Section 5.9.2.

4.7 Chapter Summary

This chapter has encompassed the discussion about knowledge, artificial intelligence, and its applications. It is followed by the specific review about Knowledge-Based System and its attributes which is used in this research to develop the KBIMSO. To provide an overall view of the development of the KBIMSO, GAP and AHP are also discussed at the end of the chapter.

The review about knowledge is focused on distinguishing among data, information, knowledge, and wisdom. The earlier term has a contribution to develop the next term in the knowledge hierarchy. To enable transformation from one form of knowledge to another form, knowledge conversion approach is introduced. This approach is very useful to retain knowledge within the organisation, make it easier to access and retrieve when needed.

The development of AI emerges with the initial idea of substituting human expertise by computers to do interaction and even make decisions. AI works through simulating computers to respond on a particular issue like a human expert. The applications of AI are variously developed such as Artificial Neural Network, Case-Based Reasoning, Genetic Algorithm, Fuzzy Logic, and Expert System, to name but a few. The latter AI application is also known as a

Knowledge-Based System, which is used in this research to develop the KBIMSO.

In KB System, facts and rules are stored in the computer as the knowledge-base. They are the resources of KB system to work and "think", as the basis of generating reasons in making decision and recommendation. To acquire the required knowledge, direct as well as indirect communications might be applied. The communication with knowledgeable people and experience users are needed to give insight into the problem discussed. Meanwhile, to help the computer to reason and find the relationship among the elements of the knowledge base, knowledge representation is required by storing and processing knowledge. Another element of KB system contributing to generating the inference is known as an inference engine. The data-driven and goal driven are two of the common methods used. These are also known as forward and backward chaining, respectively. The data-driven is intended to find and inform some particular data, meanwhile, the goal-driven is focused to find the solution.

As the KBIMSO integrates KB system with Gauging Absences of Pre-requisites and Analytic Hierarchy Process to assist the integration of maintenance strategy and operations with manufacturing and business perspectives, the discussion about GAP and AHP are also included in this chapter. GAP analysis provides a structural mechanism and problem category hierarchy to benchmark and finds the gap between the existing and pre-requisite condition. Furthermore, this analysis is used as input for AHP analysis to set the priority of improvement among multi-criteria which have been defined in the KBIMSO. After Chapter 2, 3, and 4 present literature reviews about different subjects to support the development of the KBIMSO, Chapter 5 explains the development of KBIMSO framework as the early step and guidance to develop KBIMSO model and application.

CHAPTER 5

Developing Conceptual Framework of KBIMSO

5.1 Introduction

The experts might leave the organisation and take all required knowledge to make decision away with them. Therefore, the application of a KB system to imitate the experts' ability in making decisions becomes a potential opportunity. In addition, the use of computer systems to support decision making can save time as well as provide consistent results. By considering those circumstances, this research is addressed to develop a Knowledge-Based System to facilitate decision making related to maintenance function and to ensure alignment with the manufacturing function and business strategy. This approach is called Knowledge-Based System for Integrated Maintenance Strategy and Operations (KBIMSO).

This chapter details the development process of the framework of KBIMSO as the foundation to develop the KBIMSO model to support maintenance decision making. The stages of the framework are designed by compiling, analysing and concluding from literature review, previous PhD thesis and published papers on Knowledge-Based background, related case studies, and discussions with supervisors as the academic experts.

5.2 Stage Identification of the KBIMSO Framework

The implementation of Knowledge-Based (KB) Systems has gained a huge of attention since the 1990s as a decision support tool (Wang et al., 2008). It has been widely used in the area of manufacturing management, such as performance measurement (Wibisono, 2003), supply chain (Udin, 2004), and manufacturing process (Nawawi, 2009; Mohamed, 2012). Huang (2009) noted the application of KB Systems in the information management areas such as dealing with commercial loan underwriting, logistics strategy, farm productivity, and earthquake design. Moreover, it has also been applied in the area of medical, chemical, agricultural, financial and business (Liao, 2005). It can thus be concluded that the application of KB Systems to assist decision making is a viable and proven methodology.

The role of the maintenance function to achieve expected reliability and to support performance level of manufacturing equipment makes maintenance decision closely linked to manufacturing function. Furthermore, maintenance function has been recognised as a key business driver to achieve competitive advantage. Therefore, decision making for maintenance strategy and operations needs to consider manufacturing and business perspectives into account. The integration of manufacturing and business perspectives to maintenance function is highlighted in this research, which is called Integrated Maintenance Strategy and Operations (IMSO). It is considered as a strategic process to support maintenance decision making.

The involvement of many criteria on the IMSO to obtain the appropriate maintenance decision requires a multi-criteria decision making technique and computer programming to assure a faster, accurate and realistic result. Moreover, the benchmarking process could also be accommodated by analysing the gap between the existing system and the pre-requisite condition. Therefore, the integration of a KB System with AHP and GAP to support IMSO, which is then called as Knowledge-Based System for Integrated Maintenance Strategy and Operations (KBIMSO), is considered as the suitable techniques or methodologies to be deployed to gain reliable decision making process. Based on the discussion above, there are four main stages required to develop the KBIMSO framework, as shown in Figure 5-1.

The *Strategic Stage* as the first stage is intended to identify the uniqueness of the company and its objective. It is rooted from vision and mission statements as the company's fundamental document. Vision is described as the mental picture of the desired future condition (Joachim, 2010) while the mission is intended to foster a value system, focused on the common objective, guide the teamwork, behaviour, and emotional commitment to reach the vision (Mullane, 2002). In the simple words, it can be said that vision is about where/what the company wants to be, while the mission is about how to achieve it. The vision and mission as the company's statements will direct the strategy and operations executed by each function. Thus, it will influence the strategy chosen in producing and supplying right products and services for the customers. This stage is considered to be the initial stage in the KBIMSO framework whereby maintenance as the driver of business should be referred to when executing any strategic and operational decision.

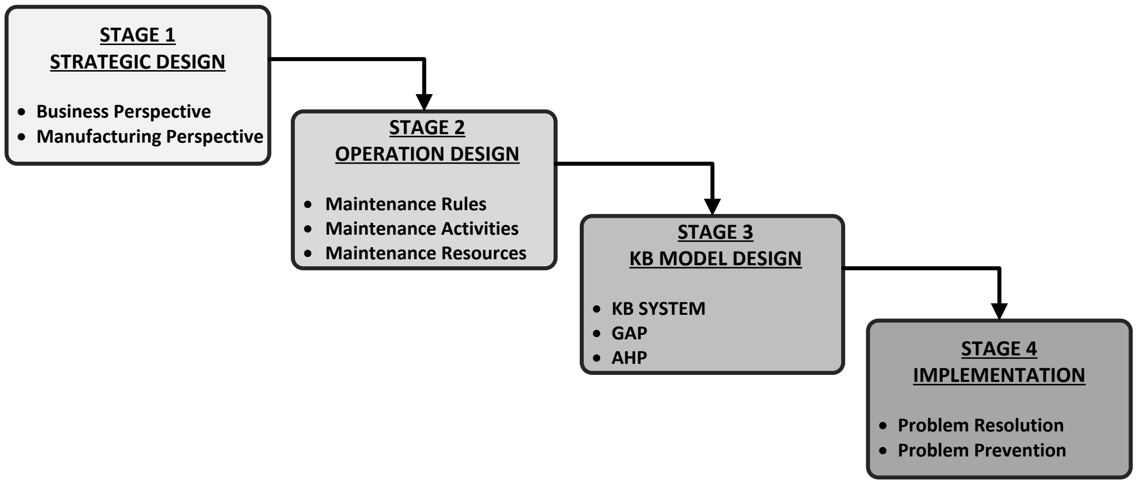


Figure 5-1 Four stages of developing the KBIMSO framework

As the statements of vision and mission are the general statements of the company for its future, it cannot be easily converted into practical guidelines for the rest of the company's members when executing their activities. To get the tangible and measurable representation, the statements need to be elaborated into strategic and operational performance. Relating the company statement into operational procedures is one of the most difficult but important tasks (Joachim, 2010). Therefore, one of the ways to communicate and translate the company's statement to the operating characteristics is that of knowing the existing company's performance (Wibisono, 2003).

Traditionally, the company performance was assessed from a financial perspective only. Considering that it will mislead the overall achievement and ignore the long-term prospective investment, many approaches have been developed to present the real performance of a company. Some recent approaches are developed for measuring performance, such as Prism, Integrated Dynamic Performance Measurement System, Performance Measurement Questionnaire, and Balanced Scorecard (BSC), to name but a few. Prism, also known as Performance Prism, is a framework and measurement model which contains 208 measures to support identification and selection of measures for the organisation (Neely et al., 2002). Integrated Dynamic Performance Measurement System, is a performance measurement system which identifies three factors of performance measurement (success, performance measures, and performance standards) of three integrated main areas of the company (management, process improvement team, and shop floor) (Ghalayini et al., 1997). Performance Measurement Questionnaire, is a performance measurement approach using the questionnaire which consists of two aspects; performance improvement and performance factors (Dixon et al., 1990). All those approaches are trying to formulate the measurable KPIs to represent the company's statement on both financial and non-financial aspects. However, to some extents, they fail to accommodate the company's uniqueness which needs more or fewer requirements.

The latter approach mentioned is considered to have many advantages than others. Balanced Scorecard suggests four perspectives which balance financial perspective assessment with non-financial perspectives of internal business process, customer, and learning and growth to measure the company achievement and its potential improvement (Kaplan and Norton, 1993) as can be seen in Figure 3-4. Although it does not specifically mention the required KPIs to measure, it provides the main dimensions which enable to represent the overall company's performance in balance. Thus, BSC is flexible enough to be modified and adjusted based on different characteristics of a particular company. Moreover, the possibility to cover the existing performance measurement and benchmarking which are the important issues in applying a new performance measurement system could be accommodated through this approach (Wibisono, 2003). Considering the ability of BSC to translate company statement into functional strategies, it is chosen as the main techniques to identify business requirements toward manufacturing and maintenance within the KBIMSO approach.

Still considering the importance to ascertain the individual features of a company, the variety of a company's characteristics are also measured by investigating the company's environment (Mohamed, 2012; Nawawi, 2009; Wibisono, 2003). The product, size of the company, number of employees, annual turnover, age of the company, number of competitors, and maintenance focused activities are some factors integrated to define its own character related to IMSO purpose. Those aspects will influence the decisions to execute the task procedures and the targets to achieve.

As the business support function, maintenance decisions should be aligned with business strategies (Pintelon et al., 2006). On the other hand, the role of maintenance as the manufacturing's logistic requires input from manufacturing to allocate maintenance tasks (Simões et al., 2011). Therefore, another aspect examined in this stage is the manufacturing perspective. All factors pertaining to manufacturing equipment performance will directly relate to maintenance. The concern of maintenance is not only for reducing the frequency of failure but also increasing the availability of plant, equipment reliability and assuring a better quality of the product (Oscar et al., 2003). Definitely, issues such as reliability, failure, process accuracy, and safety are considered as the priority issues for maintenance function (Duffuaa et al., 1999). Finally, it can be figured out that this strategic stage shows how the manufacturing and business perspectives influence maintenance decision through some essential KPIs.

After considering the strategic perspectives which influence maintenance, the next stage discussed in the KBIMSO is maintenance itself. By referring to Figure 5-1, the second stage in the KBIMSO framework is the *Conceptual Design Stage*. Since the main focus of this research is how to integrate maintenance strategy and operations decision with manufacturing and business perspectives within automotive industry environment, the discussion on this stage is commenced by identifying the required maintenance rules, maintenance activities and maintenance resources to maintain manufacturing equipment's reliability. This is based on the maintenance objective of doing all activities to keep the desired equipment performance (Dhillon, 2002b; British Standard 13306, 2010). Following that statement, the identification is continued to know where and when such activities are required (Duffuaa et al., 1999).

To execute maintenance activities, particularly related to business perspective in the frame of BSC, the resources are obviously considered with respect to budgeting and limitation (Atkinson, 2006). Hayes et al (2005) also highlighted the contribution of resources as one of the key decisions involved in strategy implementation. They emphasized unavoidable trade-offs as an option to deal with. Therefore, the optimal maintenance service might be achieved by setting priorities on tasks, resources, and their impacts on manufacturing performance.

Last but not least, the discussion about how those maintenance resources are collaborated and managed in a particular manner to gain the optimal result should also be taken into account. Besides the hardware resources to execute the maintenance actions, the software to manage and control, so-called maintenance rules, is required. These infrastructure elements cannot be separated from the structural and physical elements to gain successfulness of maintenance strategy and operations (Pinjala et al., 2006). It examines the required rules and control facilities to manage maintenance activities and maintenance resources.

Regarding the elements above, the challenge to take maintenance decisions can be figured out. There are four points which can be highlighted to reach the integrated maintenance strategy and operations within an automotive industry environment. First, determine the targets and pre-requisite conditions to be reached. Second, identify the gaps between the current condition and the pre-requisite condition. Third, decide the priority of contributed elements to achieve the optimal result as there are many elements which should be considered at the same time. Fourth, enable the computer programme to support the decision making process which deals with the complicated calculation to reach the result. Definitely, these points require the supporting techniques to work out as addressed in the next stage of the KBIMSO framework.

Referring again to Figure 5-1, the third stage of the KBIMSO framework is the *KB Model Design Stage*. To assess the current implementation towards the pre-requisite condition as mentioned at the first point above, the KBIMSO uses the *Gauge Absences of Pre-requisites (GAP)* technique and analysis. It is a technique intended to identify systematically the gap between the current and desired (benchmark) conditions (Udin et al., 2006a). Initially developed by Kochhar, et al (1991) as stated in Wibisono (2003), GAP analysis identifies five levels of gap which are categorised based on its importance and impact on the system. This technique is elaborated by Mohamed (2012) into nine levels to align it with the-nine-level of AHP methodology. The use of GAP analysis is suitable for the KBIMSO since maintenance decisions and implementations need to refer to business objectives and manufacturing equipment requirements as the main role, as well as to find the best practice of maintenance implementation. This need can be covered through finding the gap and benchmarking internally as well as externally. By implementing the GAP method, each maintenance decision and implementation can be assessed systematically towards its pre-requisite condition. It will be firmly helpful to obtain the optimal decision making process of the KBIMSO.

Considering the variety of variables involved in this KBIMSO, the decision making process needs a technique which can accommodate multi-criteria. The consistency of comparing and weighting of each variable against others is the main requirement for this need. The decision making technique used widely in different fields to deal with this need is known as Analytic Hierarchy Process (AHP) (Vaidya and Kumar, 2006). The ability to guide the decision making process by breaking down the problem, focusing on the goal, identifying the contributed criteria, structuring them into a hierarchy, and weighting those criteria consistently against others to reach the best alternative decision makes AHP a powerful decision making technique (Saaty, 1994). Moreover, its rationality and simple problem structuring make it easy to be applied. For this reason, the implementation of AHP as the multi-criteria decision making technique within the KBIMSO is chosen as the best solution.

The integration of GAP and AHP into the KB system becomes a novel and new technique in the KBIMSO. By having a number of data and information to reach a decision, the calculation is cumbersome and tedious to be handled manually (Khan and Wibisono, 2008). Those inputs will also grow rapidly and need to be stored in a systematic way to ease the retrieving and analysing process when required. Moreover, when these processes are only handled by some experts, the knowledge will be gone when those experts leave the organisation (Turban et al., 2008). To deal with this circumstance, the computerised KB system has the ability to store and retrieve knowledge in a realistic and consistent manner. After KB rules are populated, the recommendations are generated to help maintenance manager identifying critical aspects that need improvement and rectification. The priorities proposed by AHP are then structured for each level. Thus it directs how that recommendation can be executed properly.

Referring again to Figure 5-1, the last stage of the KBIMSO is the *Implementation Stage*. The implementation of the KBIMSO is split into two types, fixing the problems or preventing the problems. To deal with these needs, the Six Sigma technique has suitable methods of problem resolution and problem prevention (Stamatis, 2004). For problem resolution, there is a DMAIC method which stands for Define, Measure, Analyse, Improve, and Control. It is a powerful process technique which works as a problem structuring and improvement approach methodology (de Mast and Lokkerbol, 2012). Meanwhile, for problem prevention, there is DCOV method which stands for Define, Characterise, Organise, and Verify (Stamatis, 2004). Each step in these alternative methods is complemented with the suitable tools to execute it. Practically, they will be adjusted to get the best implementation.

Furthermore, to obtain a holistic guideline about the KBIMSO framework within automotive industry environment, each stage is discussed in more detail as the basis for the KBIMSO model to develop.

5.3 Stage 1: Strategic Design – Business and Manufacturing

The first stage of the KBIMSO framework within an automotive industry environment is the *Strategic Stage* which is shown in Figure 5-2. As mentioned previously on Section 3.4, the maintenance function is significantly influenced by business strategy vertically and manufacturing function horizontally.

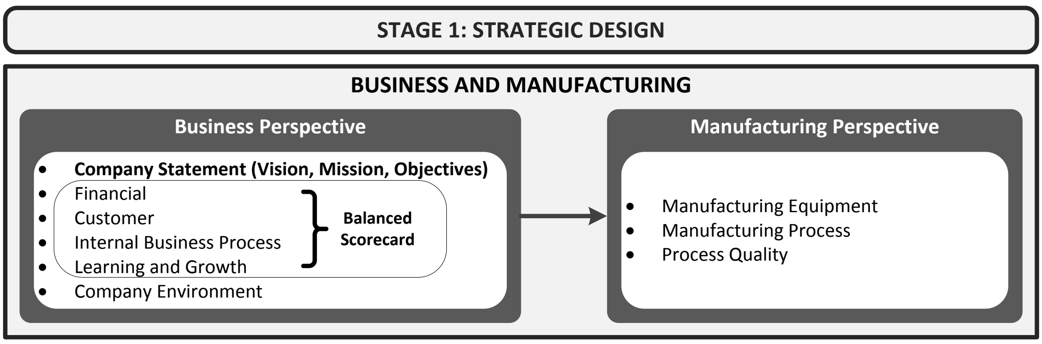


Figure 5-2 Stage 1: Strategic Design

This stage is intended to identify vision, mission, and strategy of a particular automotive company as the basis to start developing the KBIMSO. Furthermore, this stage presents the critical aspects of business and the expected performance of the manufacturing function as the guideline to develop appropriate maintenance rules and to allocate maintenance resources in order to execute maintenance activities in supporting the specified mission and strategy.

5.3.1 Business Perspective

The *Business Perspective*, as a sub-aspect of *Strategic Perspective*, is focused on the business unit level within a company. The business unit level is situated below the corporate level on the organisational strategy (Hill and Hill, 2009) as can be referred to Figure 3-1. Its strategy focuses on deciding the suitable market in which the particular product is competing, and required investment to support that decision. To figure out a holistic picture of *Business Perspective*, it has to identify all related dimensions representing business performance, through the use of BSC (Kaplan and Norton, 2005). This means that the traditional method of one-dimension of financial perspective addressed to assess corporate performance is no longer acceptable; instead, it has to be put together with other intangible aspects in balance, as shown in Figure 5-3.

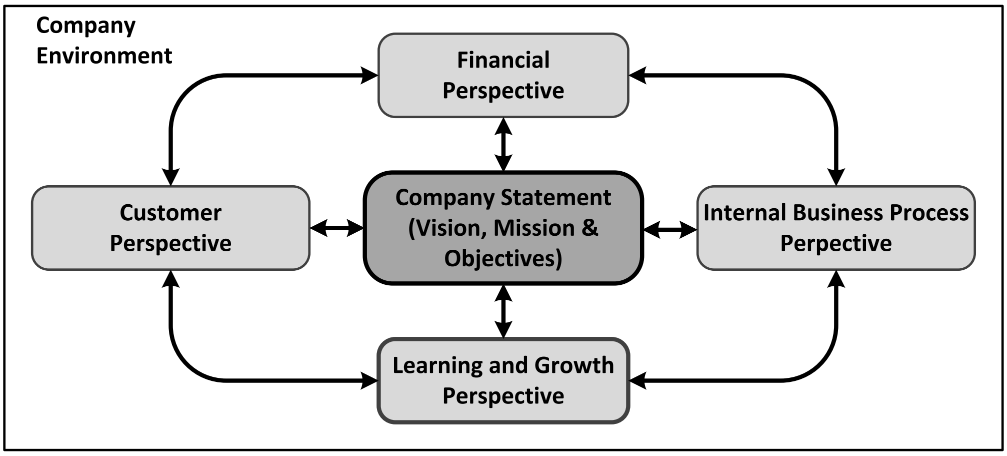


Figure 5-3 Business Perspective of the KBIMSO using BSC methodology

BSC evolves from a performance measurement tools to a strategic management system (Kaplan and Norton, 2007). By this, it means that BSC is not only able to describe the past performance of a company, but also to articulate and communicate the strategy to the entire organisation to achieve the business goal

(Kaplan and Norton, 1996b). In this research, BSC is employed to provide a guideline to translate company statement into required functional performances. Through its four-perspectives, the business strategies are aligned to functional strategies and operational requirements to determine appropriate resources, process, and control of maintenance performance.

5.3.1.1 Company Statement Analysis

The initial identification of *Business Perspective* is started from the company statement as the main direction for the company to achieve the business goal (refer to Figure 5-2). These are vision, mission, and objectives that consist of insight and core values about what the company wants to be, what the company wants to do and how to achieve them, respectively, as shown in Figure 5-4.

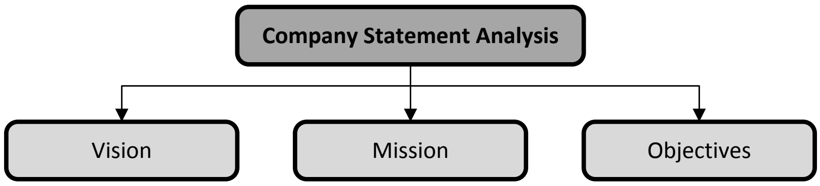


Figure 5-4 Aspects of Company Statement Analysis

The clear values on vision, mission, and objectives – which are supported by the corporate culture – will support organisation, particularly maintenance function, to clarify working relation in term of a chain of command, a delegation of authority, and span of control (Haroun and Duffuaa, 2009). Vision and mission will be useful to encourage positive behaviour and emotional commitment of employees when they are established on relevant internal policies to support them (Mullane, 2002). Despite the vision and mission statements are the most powerful statements at the top of company intention, it cannot easily guide and direct the operational actions (Kaplan and Norton, 2007). Therefore, to internalise these important statements, they need to be elaborated into some measurable objectives through the assistance of BSC approach. The existence of BSC in this KBIMSO is intended to expand company statement into four main perspectives of BSC, identify the current state of the company on each perspective, and assess the performances of the company compared to its benchmarks as the basis to develop a suitable recommendation for maintenance function.

5.3.1.2 Financial Analysis

Financial Analysis is the preliminary aspect to be investigated to reveal the company's ability in offering the qualified basis for all functions of the company to operate appropriately and facing business competition. It is intended to analyse the company's overall performance and assess its current financial standing as the way to know the profitability of the company, its position against standard criteria and the possibility of potential improvement (Brealey et al., 2001). Financial statements are the company tools to communicate financial performance of the company to the investment community. Those are the company-issued accounting reports about past financial performance which are issued periodically, either quarterly or annually (Berk and DeMarzo, 2011). There are two formal financial statements required in the KBIMSO model; those are *Balance Sheet* and *Income Statement*, as shown in Figure 5-5.

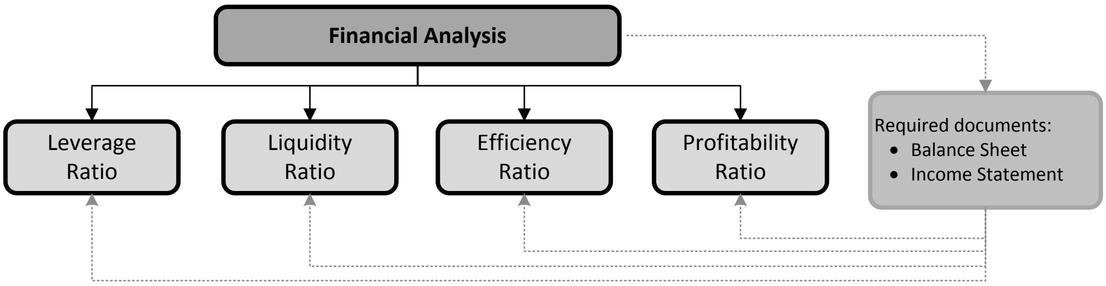


Figure 5-5 Aspects of Financial Analysis

These two financial statements will reveal four important ratios to evaluate the financial health of the company. Those are *Leverage Ratio*, *Liquidity Ratio*, *Efficiency Ratio*, and *Profitability Ratio* (Brealey et al., 2001; Bertoneche and Knight, 2001). *Leverage Ratio* indicates the ability of the company to fulfil long-term debt obligations, while *Liquidity Ratio* informs the ability of the company to fulfil short-term debt obligations. *Efficiency Ratio* is used to evaluate the operating efficiency of the company with respect to the capital. Finally, *Profitability Ratio* reveals the ability of the company to create value and generate revenues in excess of expenses. For this reason, the latter one is closely related to *Return on Investment* (ROI) measurement.

5.3.1.3 Customer Analysis

The main idea of *Customer Analysis* is emphasised on how the company can present its best performance in producing product and service from the customer's view (Kaplan and Norton, 2007). The measurement can be conducted by investigating how many customers use a particular product and service, and how satisfied they are with the performance of such product and service. These can be ascertained from customer satisfaction analysis and market share, as shown in Figure 5-6.

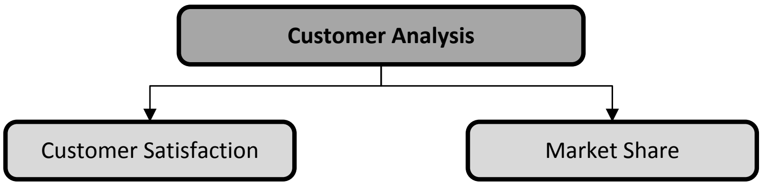


Figure 5-6 Aspects of Customer Analysis

Customer Satisfaction

To achieve customer satisfaction, there are at least three main factors of which the company needs to fulfil; those are response time, product quality, and price. Response time refers to the lead time needed to meet customer's demand since the order is received until the product is delivered to the customer. The response time can also be categorised into product quality in terms of how qualified is the company to provide the product on the specified time. Nevertheless, in this discussion the response time is separated from product quality to avoid overlapping and to emphasise the time of delivery aspect; meanwhile, product quality is focused on product specification.

From product quality perspective, a product encompasses some dimensions of quality that are expected to be provided by a company to satisfy its customers (Garvin, 1987), as shown in Figure 5-7.

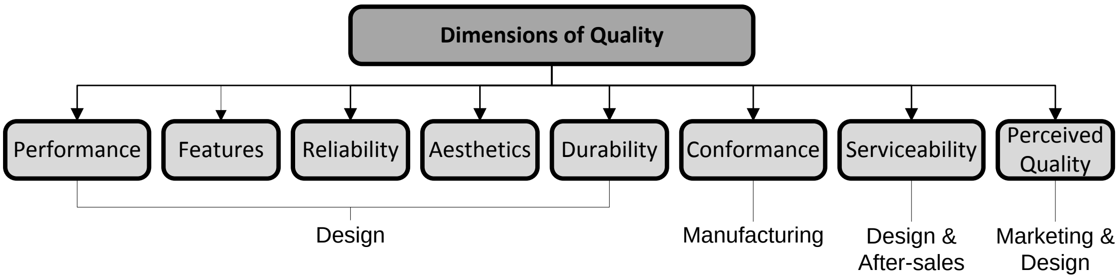


Figure 5-7 Dimensions of quality

To gain an appropriate perceived quality, some functions are responsible either in the design, performance, marketing or after sale service (Hill and Hill, 2009). Although the dimensions of design are handled by the design function through interaction with research and development function, the execution of the particular design still needs to deal with maintenance function. Such design is then translated and represented into the dimension of conformance which represents the degree of product to be manufactured to the specified specification. Therefore, those dimensions relate to manufacturing and thus to maintenance as well. Measurement of the degree of conformance will be discussed in detail in the *Manufacturing Perspective*.

The last aspect regarding *Customer Satisfaction* is the price. It relates to the competitive price decided by the company for its particular product against the competitor, within a similar level of quality. The chosen product, either special or standard, influences the determined price. The customer will assess the conformity between the price they pay towards the quality of product and service they receive. The competitor's price on a similar product is also required to be considered in deciding a competitive price for such product.

Market Share

Achieving expected market share is closely related to how the company produces the products which meet the customer satisfaction. Market share represents the proportion of acquired market against the available market. It will be easily measured once the market segment has been specified (Kaplan and Norton, 1996a). The market segment will classify the groups of customer with the similar purchasing behaviour (Kotler and Armstrong, 2008). Identifying market segment helps the company to decide the positioning strategy against its competitor by creating a favourable perception of the product in a particular market segment (Saleh, 2007).

Referring to the market share, the marketplace is considered to indicate the area of market covered by product. It could be classified as the restricted market and the global market. Restricted market refers to a local market where the customers tend to be homogeneous within a national boundary and easily clustered for segmentation strategy purpose. Meanwhile, the global market corresponds to international market which also faces the diversities of economic, cultural, geographic, and technology (Hassan and Craft, 2005). When the company decides to get into the global market, such company should be ready with a complex segmentation strategy accompanied with a variety of products to accommodate different needs and favours of customers.

Regarding the above explanations, it can be concluded that market share enables a company to know the customer acceptance and satisfaction of its products and services among other competitors. It plays as one of the keys to figure out the actions required by the company in producing its products and services. Therefore, market share is considered as the important KPI to be assessed in the customer perspective.

5.3.1.4 Internal Business Process Analysis

Internal Business Process Analysis discusses how a company excels its core business to meet customer and shareholder satisfaction (Kaplan and Norton, 2007). In other words, this perspective focuses on the process by which the company fulfils the customers and shareholder’s needs. Focusing on both customers and shareholders mean considering two different perspectives at the same time. Obviously, customers want to get a quality product and service at the acceptable price, whereas the shareholders want to achieve high dividends for their investment. For these reasons, the company is required to optimise its internal business process to meet these expectations. It is started from the process of research and development in creating the product, continued with producing the product, and ends with providing the after-sale service (Kaplan and Norton, 2005). The KPIs used to investigate the efforts of the company throughout the internal aspects are shown in Figure 5-8. Since the KBIMSO integrates business, manufacturing and maintenance perspectives, the discussion of *Manufacturing Process* aspect is emphasized in the *Manufacturing Perspective* in Section 5.3.2.2. Meanwhile, the *Internal Business Process Analysis* is only discussing *Product Development* and *After-Sale Service* aspects.

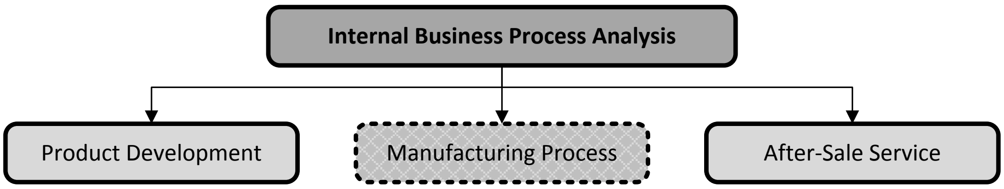


Figure 5-8 Aspects of Internal Business Process Analysis

Product Development (Innovation)

Innovation is definitely required in the business process to realise the customer needs. After deciding the market segment, the company needs to design and develop certain products for such segment. For this need, marketing research and development activities take the major portion in the aspect of innovation. Product development proceeds from a market research to understand the marketplace, market segment identification, the strategy to assimilate the product and the suitable price towards competitors. Product development could relate to the shape, function, colour, storage of product, and so on. The main point for innovation in *Internal Business Process Analysis* is transferring identified customer needs into satisfied customer needs (Kaplan and Norton, 1996a).

Another aspect that cannot be separated from innovation is an improvement (Kaplan and Norton, 1993). The improvement is emphasised on research and development to add the value of existing product and service to increase customer satisfaction by increasing the product performance (Alsyouf, 2006). There are three aspects should be continually improved to deal with product competitiveness; reduce cycle time, increase quality, and reduce cost (Koufteros et al., 2005; Ragatz et al., 1997).

After-Sale Service

After considering the physical performance and appearance aspects to yield a quality product to satisfy the customers, the company cannot ignore after-sale service to maintain customer loyalty. It is considered as a crucial part of winning the business competition (Wibisono, 2003). It could be defined as the market strategy to extend traditional perspective of the product by providing additional service in order to gain sustainability (Baines et al., 2007). The services provided could be keeping the availability of spare parts, customer service centres, repair and return, warranty, etc.

5.3.1.5 Learning and Growth Analysis

Learning and Growth Analysis focuses on the aspects which need to be improved by the company to achieve a long-term growth. The company needs to upgrade the existing capability to achieve the breakthrough performance (Kaplan and Norton, 1996a). The KPIs for this perspective are represented through employee’s skill and satisfaction, technology, procedures and environmental issue, as presented in Figure 5-9.

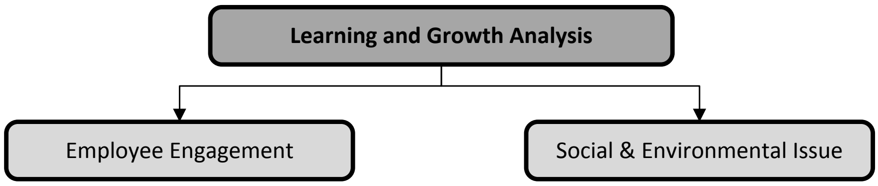


Figure 5-9 Aspects of Learning and Growth Analysis

Employee Engagement

The learning and growth process to increase skill and satisfaction of employees is necessary to keep a healthy business atmosphere. The satisfied employees are the important assets of the company. Although automation and technology grow over time, the role of human as the centre of activities cannot be ignored. To acquire today’s sophisticated technology, the employees have to be equipped with upgraded skills and knowledge through training and skill improvement. Moreover, the dynamic change in business competitiveness also makes intellectual assets as the most valuable property belongs to the company. This fact drives the company to maintain the employee’s satisfaction. Employee satisfaction can be represented by employee turnover, absenteeism, and leadership (Wibisono, 2003). Employee turn-over shows how long the employees retain within the company. This KPI represents the integrity and loyalty of employee. The integrity of the employee can also be assessed through rate of absenteeism. Meanwhile, leadership is critical for encouraging and directing entire elements of the organisation to reach the aim of the company.

Safety is one aspect that cannot be separated from employee engagement. The work safety issue is closely related to work environment, employee’s skill, equipment’s performance, and maintenance (Varonen and Mattila, 2000; Sharma et al., 2011). In turn, it will affect the quality, productivity, and profitability (Parida and Chattopadhyay, 2007). The safety concern could be evaluated through the number of complaints and the number of accidents happened in a period of time, the causes of the accidents, and what actions taken by the company to avoid and deal with the accident.

Achieving better performance cannot be separated from procedure improvement. To deal with advanced technology and rapid change in business competition, work and organisational procedures should always be aligned (Kaplan and Norton, 1996a). The learning and growth process continues through practising and refinement of procedures. Procedure revision and adjustment to current technology and situation are directed to gain flexibility and faster responses.

Another aspect which influences employee engagement is corporate culture. It becomes important to be counted as it influences business philosophy, leadership, decision-making criteria, and ways of working together (Surroca et al., 2010). One important aspect considered in corporate culture is knowledge sharing. It is an activity to ensure that the regeneration process of knowledge is continued. It could be held formally as well as informally to build good relationships and comfortable work environment among employees as a team and to share explicit and tacit knowledge (Sánchez et al., 2013). It also contributes to convert tacit into explicit knowledge so the knowledge embedded within people might be documented and stay remained within the organisation (Turban et al., 2008).

Social and Environmental Issues

The last KPI considered in this perspective is social and environmental issues. Environmental and social issues should be handled together by government, company, and citizens (Crowther and Aras, 2008). However, Drucker (2011) emphasised that the business successfulness depends on the contribution of the company to the society by managing social impact and taking social responsibility. Some social issues such as scarcity of resources, sustainability, safety and "go green" for environmental impact rise to be one of the competitive priorities (Alsyouf, 2006). The concern to reduce emission, pollution, as well as participate in facing climate changing should be taken into account (Ledoux et al., 2005).

5.3.1.6 Company Environment

The company environment is included in KBIMSO to recognise its role in identifying the environment in which the company is operating in and to describe the position of company among its competitors (Wibisono, 2003). It is also used to assist the appropriate decision for functional strategy. Some aspects observed are business competitiveness (in term of age of the company, size of the company based on the number of employees and financial information, and market share), maintenance aspects, and corporate sustainability, as illustrated in Figure 5-10.

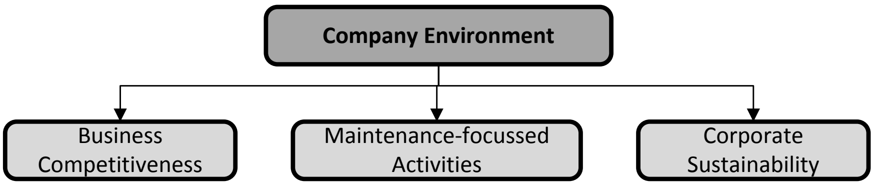


Figure 5-10 Aspects of Company Environment

Age of Company

Age of company is important to measure the maturity of the company (and its products) to compete in business. It shows how long a company has been involved and concentrated in such business. Age also comes with experience and resilience to keep up with the competition. A 5 years old company is classified at the growth level; a more than 5 but less than 15 years old company is classified at the sustain level; and a more than 15 years old company is classified at the harvest level (Mohamed, 2012; Nawawi, 2009). The compilation of this classification is presented in Table 5-1.

Table 5-1 Classification of company based on age, adapted from Mohamed (2012) and Nawawi (Nawawi, 2009)

Age of Company	Business Stage
≤ 5 years	Growth Level
5 – 10 years	Sustain Level
> 10 years	Harvest Level

Size of Company

Number of employees and financial information are the ways to classify size of the company, as shown in Table 5-2. Employees are considered as all staff that work in the company for full-time, seasonal time and part-time, and are calculated proportionally where a full-time staff is counted as one employee, while seasonal time and part-time are counted in fraction (European Commission, 2003). The performances of a company which are reflected by the number of employees are labour productivity (sales/employee), financial performance (profit/employee), labour turnover and labour qualifications (Nawawi, 2009).

Financial information on either Annual Turnover or Annual Balance Sheet Total is also required to identify the size of a company. Along with the number of employees, size of the company is distinguished into four categories, which are large, medium, small or micro company. The European Commission (2003) released threshold for each category which took effect from 2005, as shown in Table 5-2.

Table 5-2 Classification of company based on size, adapted from European Commission (2003)

Classification of Company	Number of Employees	Annual Turnover	or	Annual Balance Sheet Total
Large	≥ 250	> € 50 million	or	> € 43 million
Medium	< 250	≤ € 50 million	or	≤ € 43 million
Small	< 50	≤ € 10 million	or	≤ € 10 million
Micro	< 10	≤ € 2 million	or	≤ € 2 million

From this table, a company is classified as a large company if it has at least 250 employees or more and has a financial statement of either annual turnover more than € 50 million or annual balance sheet total more than € 43 million, and so on for medium, small and micro companies. Those thresholds are used later in this research to indicate a company's economic conditions in taking some investment decisions on maintenance function.

5.3.2 Manufacturing Perspective

As a function that is closely related to maintenance, most of the manufacturing decisions correspond to the maintenance function. The roles of maintenance are focused to maintain availability, reliability, and safety of manufacturing equipment for a seamless manufacturing process (Waeyenbergh and Pintelon, 2002). There are three main aspects of manufacturing highlighted in the KBIMSO framework to show its close relation with maintenance, as illustrated in Figure 5-11.

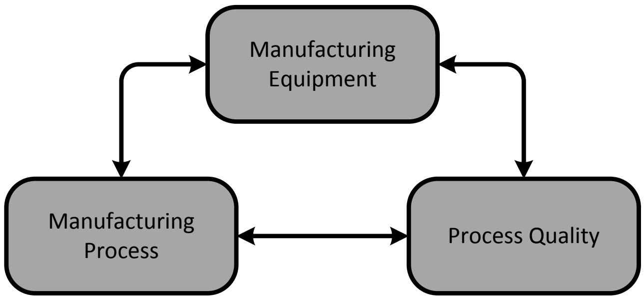


Figure 5-11 Manufacturing Perspective of the KBIMSO

The main concern of maintenance in the manufacturing element is the equipment itself. The level of automation of each equipment corresponds to the maintenance treatment required to ensure such devices can work on the desired performance. This condition is influenced by the increment of integrated manufacturing implementation, such as Advanced Manufacturing Technology (AMT), Just-In-Time (JIT), and Total Productive Maintenance (TPM) (Pinjala et al., 2006). Along with this, manufacturing process and process quality are also claimed to have critical interaction with maintenance (Al-Najjar, 2007). The seamless process and expected quality depend on how well the performance of manufacturing equipment is in executing the assigned tasks. Therefore, manufacturing equipment, manufacturing process, and process quality are the main considerations when maintenance strategy is proposed.

5.3.2.1 Manufacturing Equipment

Automation level of manufacturing equipment is influenced by the type of industry and type of product in which the company is operating in. There is highly automated, semi-automated and less-automated equipment that might be used in production process. The maintenance function will be required for different expectation according to the quality level required, the automatic level of equipment used, and the advanced technology adopted.

The performance of manufacturing equipment as part of manufacturing process could be indicated by measuring productivity, flexibility, and maintainability of such equipment. The selection of equipment should be based on its ability to produce the expected output with minimal input. It also has to be flexible to combine with other equipment, and adaptive with the fluctuation of demand. Obviously, the selection of equipment should consider how to treat and maintain such equipment to retain its designated function.

5.3.2.2 Manufacturing Process

Manufacturing process is a converting process of material, information and energy into product or service for a large scale of customer (Burrill and Ledolter, 1999). There are three important aspects that need to be improved regarding manufacturing process, which are productivity, quality, and safety. Productivity is defined as the ratio between produced outputs in a period of time to the total of required inputs to yield such outputs (Alsyouf, 2007). The utilisation of valuable and limited resources in an effective and efficient manner addresses the productivity issue to the long-term profitability concern of the company (Al-Najjar, 2007). Moreover, the discussion about productivity in a manufacturing process involves personnel skill, quality, equipment reliability, and maintenance.

Discussion about manufacturing process cannot be separated from the layout. The decision of manufacturing process will influence the layout adopted because the different process requires different layouts to gain an effective and efficient process. The manufacturing process is classified into the following categories (Mohamed, 2012), as presented in Figure 5-12.

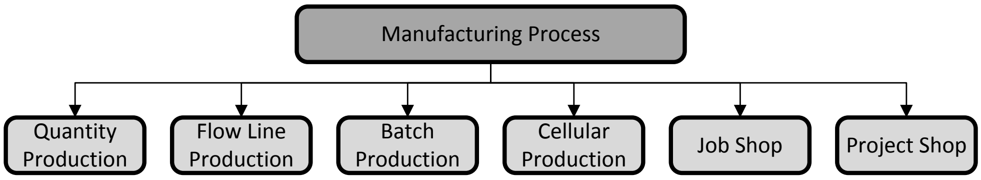


Figure 5-12 The classification of manufacturing process (adapted from Mohamed (2012))

This classification is arranged based on how the products are treated in the manufacturing shop floor from the raw material to be finished goods. It influences the way of communication among workstations and overall layout of the shop floor. The decision of the chosen manufacturing process also depends on the variety and volume of production. In term of high volume but low variety, quantity production or flow line production is chosen. Instead of another extreme, job shop or project shop production is chosen for low volume but high variety.

Following the above explanation, the important aspects to ensure the performance of manufacturing process are coordination, process flow, and information flow. Coordination among people on different functions is required to provide a seamless manufacturing process. Coordination with maintenance function could develop the reasonable process and layout to optimise the performance of manufacturing equipment. The process flow is required to observe the movement of material or work-in-process product, meanwhile, information flow is intended to indicate the communication which follows the movement of physical goods, such as demand of volume, demand of variety, and quality (Schonberger, 2013). After all, the performance of manufacturing process could be measured through on-time delivery, manufacturing life cycle, time to make changeovers, and downtime.

5.3.2.3 Process Quality

Quality is an important part to be considered in the manufacturing perspective. Different from quality indicator mentioned in *Customer Perspective* to examine customer expectation regarding product quality, the quality indicator in *Manufacturing Perspective* is emphasised on process quality which ensures that the process taken to produce the product reaching the expectation.

Process quality is an important issue in business sustainability. As the key to competitiveness, business performance is represented through the ability to deliver a quality product (Wibisono, 2003). The manufacturing process to produce a quality product is influenced by the manufacturing equipment's performance, thus related closely to the maintenance performance. Duffuaa et al (1999) noted that well-maintained equipment will produce consistent quality and reduce scrap. Overall, the quality control in the manufacturing process could be measured through conformance to specification, reject rate, scrap, rework, and, material waste.

5.4 Stage 2: Operation Design – Maintenance

The preliminary *Strategic Stage* on *Stage 1* is treated as the input to figure out the general description of what the existing condition has been reached by the company and its orientation for the future. This second stage is intended to sharpen the focus of research to maintenance subject. By employing the sources of information from the previous *Stage 1*, this *Stage 2* (namely *Operation Design Stage*) details the important aspects of maintenance function for generating strategic and operational decisions. Those aspects are highlighted in Figure 5-13.

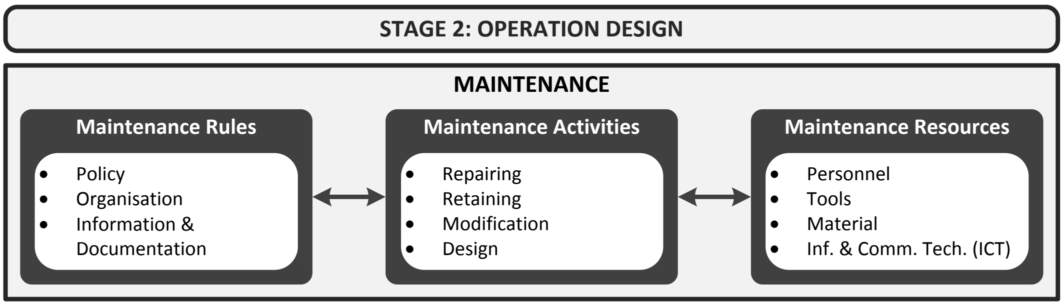


Figure 5-13 Stage 2: Operation Design

In examining the *Maintenance Perspective*, there are three broad maintenance aspects taken into account. Firstly is *Maintenance Rules,* to manage the maintenance activities and maintenance resources in order to achieve the optimal maintenance performance. Secondly is *Maintenance Activities,* to execute maintenance tasks. This aspect discusses basic activities of maintenance as the manufacturing support function to maintain manufacturing equipment performance. Thirdly is *Maintenance Resources,* to do those activities. It consists of some physical resources which contribute directly to complete maintenance process. These three aspects and their KPIs are discussed in more detail in the following section.

5.4.1 Maintenance Rules

Maintenance rules as the guideline to perform maintenance activities and maintenance resources are important to support maintenance performance. Hill and Hill (2009) noted that the companies with the same resources might reach a different degree of achievement on their business performance. It is caused by a different combination of rules and cultures adopted that influence the exploration of resources to meet the objective. Maintenance rules in the KBIMSO encompass three aspects; policy, organisation, and information and documentation, as shown in Figure 5-14.

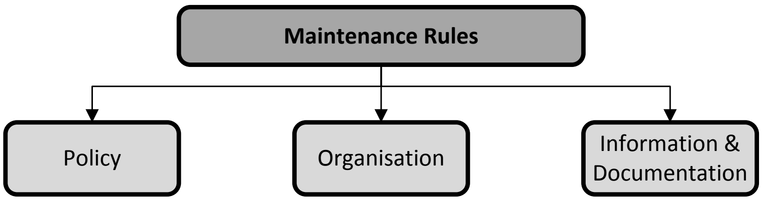


Figure 5-14 Maintenance Rules Classification

5.4.1.1 Maintenance Policy

Maintenance policy is one of the most important elements required for maintenance function (Dhillon, 2002b). The classification of maintenance policies has been discussed in Section 2.4. The different roles and characteristics can give a clear understanding of maintenance programs and its implementation. Maintenance policy acts as the guideline to perform maintenance strategy and operations. To obtain the best practice of maintenance, maintenance policy has to be obvious, comprehensive and understood by entire maintenance personnel.

5.4.1.2 Maintenance Organisation

Maintenance organisation can be classified generally into centralised and decentralised organisation. Centralised maintenance organisation is implemented through integrating all maintenance service into a central administrative server, while decentralised maintenance organisation is represented through disaggregating maintenance services based on area or type of service (Dhillon, 2002b). However, most of the companies mix these kinds of organisation on their maintenance implementation to get the optimal benefits of both. Regardless of how to extend the proportion of centralisation and decentralisation, the company has to be clear about the responsibility and authority of each server, and the mechanism of reporting and controlling of personnel though vertical line (HajShirmohammadi and Wedley, 2004).

After all configuration of maintenance organisation, the company might find that outsourcing could be another solution. The issue of outsourcing appears due to the limitation of the company's resources and capacity to cover all maintenance tasks (Hayes et al., 2005). To some extent, the company wants to focus on its core competency instead of maintenance (Tsang et al., 1999). On the other hand, outsourcing could be chosen due to the ability of outsourcing company to perform an effective maintenance time and cost based on their learning experience and specialisation (Tarakci et al., 2009). The decision of which maintenance tasks are outsourced and which ones are executed by in-house maintenance service requires the integration examination among business, manufacturing, and maintenance.

5.4.1.3 Maintenance Information and Documentation

The collection of data and information will be used to create knowledge as the references for maintenance personnel to make decisions and take actions (Pomerol and Brézillon, 2001). The information and documentation are required to ensure that information is complete, available, and easy to access. The important aspects of maintenance documentation are collecting, storing, presenting, and retrieving of information. These aspects are required to document job report and equipment data history (Duffuaa et al., 1999). These documents can record downtime, repairing time, condition of equipment, work done, and required material. Job report is intended to take documentation from employee's perspective as a subject of maintenance, while equipment data history presents information from equipment as an object of maintenance.

5.4.2 Maintenance Activities

The *Maintenance Activities* discussed in the KBIMSO are the key activities of maintenance to complete maintenance tasks in order to increase the entire life cycle of manufacturing equipment by ensuring availability, reliability, and safety of such equipment (Waeyenbergh and Pintelon, 2002). They are classified into repairing, retaining, modification, and design activities, as shown in Figure 5-15. These maintenance activities are sorted from the basic treatment to the advanced treatment of maintenance.

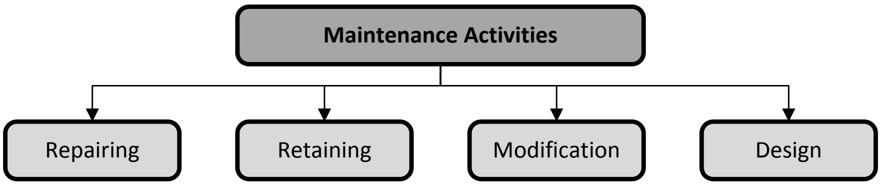


Figure 5-15 Maintenance Activities Classification

5.4.2.1 Maintenance Repairing Activity

Repairing activity in the KBIMSO is directed as a follow up of monitoring equipment condition. In fact, although the preventive maintenance is always performed regularly to retain the performance of manufacturing equipment, such equipment will experience deterioration, failure, or breakdown during their lifetime. To deal with this problem and minimise the risk and loss, repairing activity should consider three important things: priority, procedure and cost efficiency. Prioritisation is decided by considering the impact of equipment availability towards overall manufacturing process, in term of capability and safety (Dhillon, 2002b). Therefore, prioritisation is to sort out from the most serious and immediate impact to the negligible impact regarding production target and safety. Maintenance procedures should be implemented consistently to avoid unpredictable failure and equipment breakdown before its expected lifetime. By this, repairing activity only comes as the result of early detection of a potential failure, instead of a reactive action of breakdown. After all, repairing decisions refer to cost analysis by comparing cost and benefit of repairing against replacement. In case the repairing cost is higher than potential benefit, the run-to-failure approach might be considered as an option which is continued by replacement.

5.4.2.2 Maintenance Retaining Activity

Retaining activity includes inspection, servicing, calibration, testing, alignment, adjustment, and installation (Dhillon, 2002b). All tasks are known as prevention treatment to avoid failure by maintaining and monitoring equipment condition to keep it working on its expected performance. Referring to maintenance policy classification, repairing activity encompasses preventive as well as predictive maintenance. There are some KPIs that should be considered to optimise the retaining activities, which are work planning, work scheduling, and work controlling (Gulati, 2013). Work planning, scheduling, and control are important to ensure that required activities to retain manufacturing equipment performance are identified, having a clear schedule and procedure, addressing adequate resources, and under control.

5.4.2.3 Maintenance Modification and Design Activities

Initially, these activities are implemented on Total Productive Maintenance (TPM) concept to avoid losses and increase productivity (Waeyenbergh and Pintelon, 2002). Modification and design in maintenance could be done for both new and existing equipment (Swanson, 2001). To gain the success in executing these activities, there are three key factors that should be fulfilled; teamwork, information, and comparative analysis. As teamwork is the main key to modification and design activities, maintenance personnel have to collaborate with other personnel from different disciplines, such as production and engineering departments. The team members discuss and decide what kind of modification or design is required to gain the new specification of equipment. Information about the performance of existing equipment, materials, workplace, and operation is needed to identify what modification and design are needed to improve the performance. Different from retaining and repairing activities that focus on keeping manufacturing performance based on its designed function, modification and design activities are intended to increase the manufacturing performance. Therefore, it is important to check whether the new specification of equipment can increase performance regarding output, safety, and flexibility.

5.4.3 Maintenance Resources

Maintenance resources are defined as all maintenance elements contributing directly to execute maintenance tasks. The tangible maintenance resources consist of personnel who do maintenance tasks, tools which are used to support maintenance tasks, material required for replacement, and information communication and technology (ICT), as shown in Figure 5-16.

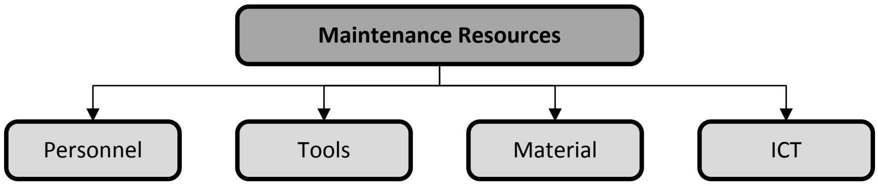


Figure 5-16 Maintenance Resources Classification

Considering the scarcity of resources and environmental issues, the decision about maintenance resources need to be referred to “prioritisation” and “trade-off” approach (Alsyouf, 2006). This condition challenges maintenance function to find the best combination of available resources to optimise achievement in order to meet all demand through prioritised manner.

5.4.3.1 Maintenance Personnel

Different from manufacturing department, the number of maintenance personnel increases due to automation complexity. However, all sophisticated technologies still require humans to manage and operate them. As the centre of all manufacturing and maintenance activities, the personnel should be equipped with adequate education and skill to operate and maintain such advanced technology equipment. In fact, some studies reveal that 40 percent of failure is caused by human errors (Gulati, 2013). Therefore, skill improvements become an important competitive priority.

As two integrated functions, manufacturing and maintenance cannot be fragmented. Thus to discuss personnel as the maintenance resources, the maintenance tasks cannot be assigned to maintenance personnel only. As the front-line who directly interact with equipment, manufacturing personnel have to be able to perform basic maintenance such as cleaning and monitoring. Their knowledge about characteristics of such equipment, how to operate it safely, and how to detect failure and abnormality is very significant (Gulati, 2013). Furthermore, any information is communicated to maintenance personnel to take the follow-up actions.

Job description is another part to be considered to gain an optimal maintenance personnel performance. It informs the responsibility of each personnel or team to any kind of equipment and how far they can make a decision on their authority's area related to their job. A clear job description also enables to trace who did the treatment and what kind of treatment is given to equipment as the basis to decide skill improvement training or promotion.

5.4.3.2 Maintenance Tools

As manufacturing has equipment to produce the product, maintenance also requires the equipment to support maintenance work. Equipment and tools are provided based on demand from manufacturing function. The availability and conformity of maintenance equipment and tools are referred to regularly planned maintenance activities. They could be in the form of repairing tools, deterioration capturing sensors or special equipment for special needs.

5.4.3.3 Maintenance Material

Material or spare parts in maintenance refer to required inventory to support maintenance process to retain and return production equipment to their desired capacity. It might be a general nut and bolt, or lubricant, or moreover a unique part that should be ordered to the original equipment manufacturer (OEM). Considering that material cost could reach approximately 30 to 40 percent of total direct maintenance cost (Dhillon, 2002b), this issue has an important impact on effective and efficient maintenance practice. The correct specification of spare parts could minimise false action, delay, and secondary failure. Therefore, communication and coordination internally with the manufacturing function and externally with the supplier are required.

The availability of spare parts is influenced by criticality (Duffuaa et al., 1999). The spare part might be the one with a high impact which is critical to the production process as it can cause production line stops. For spare parts which have a moderate impact on the production process, they can be classified into medium impact. Otherwise, the spare parts are categorised into low impact when they can be substituted with others or delayed to be repaired without significantly influencing the production process.

The availability of spare parts will also be determined by the frequency of use, which is high moving, medium moving, or slow moving. Level of inventory for each type of spare part will be different and should be treated properly as they are highly related with inventory cost, such as ordering cost and holding cost, otherwise, unavailability of such spare parts will lead to unfulfilled demand or delay in delivery.

5.4.3.4 Maintenance Information and Communication Technology (ICT)

The rapid growth of technology makes the competition more challenging. Adopting the latest technology to get the effective and efficient performance is required, both for information and communication technology (ICT) and advanced manufacturing systems. Therefore, the implementation of technology encompasses managerial system, manufacturing process, quality control, maintenance and covers the entire elements of the company. The application of technology can be represented for instances through data accuracy, real-time data availability, reducing lead time, and increasing quality.

The existence of ICT in maintenance is beneficial to increase flexibility, response, and analysis to support decision making. One of the ICT tools in maintenance is Computerised Maintenance Management System (CMMS). CMMS is an information system tool to support maintenance (Duffuaa et al., 1999). Basically, it is used for work order functionality (Mather, 2005), where it records the activities and resources required to execute maintenance tasks, and then arranges those activities with required resources. Therefore, this ICT tool encompasses planning and scheduling, inventory control, equipment history, and performance report (Duffuaa et al., 1999). Regardless of the ICT tool used within the company, the performance of such tool to support maintenance should be measured. The KPIs used are information accuracy, ease of use and time effective. Information accuracy is important to get all variables counted in making a decision. It also contributes to avoiding "*garbage in, garbage out*". Meanwhile, the ICT tool should be user-friendly, both to input the information and present the result. Lastly, such application could save time and assure accuracy compared to manual procedures.

5.5 Stage 3: Knowledge-Based Model Design – Hybrid KB System

There are three techniques which are embedded in building the hybrid KBIMSO; AHP, GAP, and KB system. Each technique has a different role which contributes to support decision making for the KBIMSO, as presented in Figure 5-17. In GAP analysis, the gap between current condition and prerequisites condition is defined by Problem Category (PC). The PCs are rated and described from the most critical to the less critical one toward the system performance. The model design stage is then incorporated into benchmarking process through GAP approach. To get a proportional comparison and PC assigned to each KB rule, the benchmarking is conducted internally and externally. Internal benchmarking is oriented to compare existing performance with its standard or expected performance. Meanwhile, external benchmarking is comparing such system to other systems outside the company. This external benchmarking is beneficial to obtain information about how others achieving their success on the particular issues. All KB rules from Level 1 to Level 5 of KBIMSO model are attached to certain PC rate.

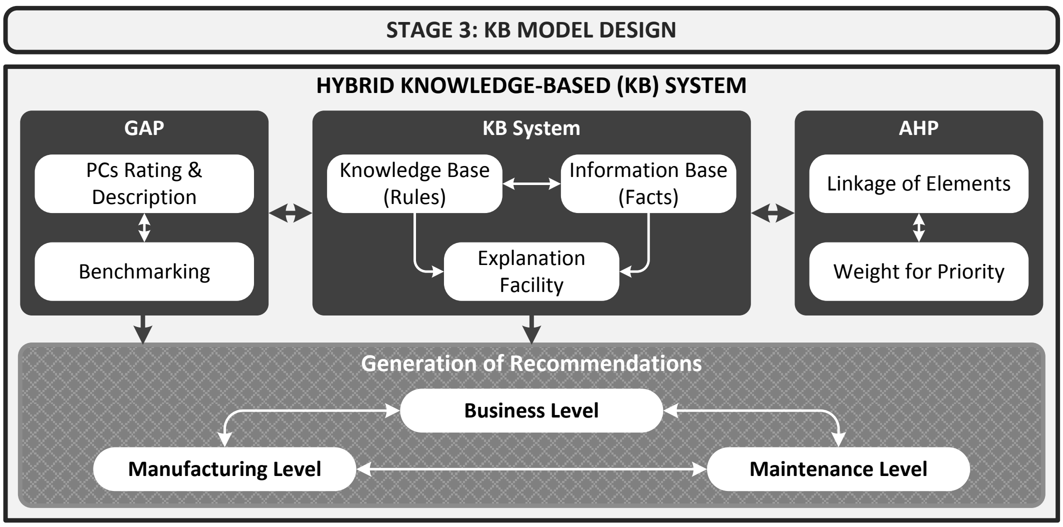


Figure 5-17 Stage 3: Knowledge-Based Model Design

Due to its capability to accommodate quantitative as well as qualitative criteria, AHP analysis is chosen to provide such priority's recommendation to support the integration of elements of the KBIMSO through two main concerns, linkage the elements and weight for priority (Milana et al., 2017).

At the end of each module, a comparison is examined among sub-modules, and at the end of each level, a comparison is examined among modules to propose rectification and improvement priority for organisation performance which impacts specifically to maintenance performance. The explanations of the use of AHP, GAP in the KB System to support the KBIMSO are detailed in Chapter 6.

5.6 Stage 4: Implementation – Implementation Alternatives

The implementation stage is contained in the KBIMSO framework to give a holistic appearance of how such framework will be addressed systematically for the achievement of objectives. The consistent and well-organised implementation will lead to successful achievement of the objective of either problem resolution or problem prevention. In this KBIMSO framework, the implementation is addressed to the output of KBIMSO, which is recommendation. There are two types of implementation approach provided, which will be adjusted to specific needs of maintenance problems in different cases, as shown in Figure 5-18.

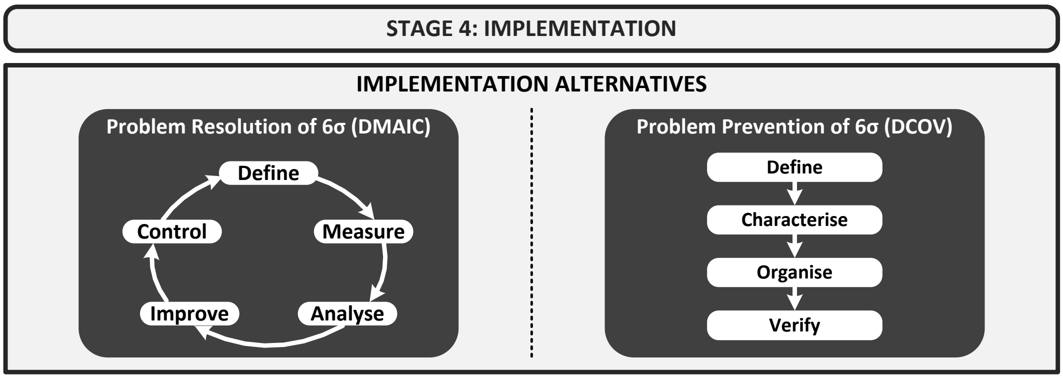


Figure 5-18 Stage 4: Implementation

Those are DMAIC (Define, Measure, Analyse, Improve, Control), and DCOV (Define, Characterise, Organise, Verify). The DMAIC and DCOV are the Six Sigma methods which are initially used to handle the problem of quality as the main concern to meet customer's satisfaction. During its development, these approaches are adapted to other fields as the way to gain improvement in system implementation.

5.6.1 Problem Resolution through DMAIC

The implementation stage for problem resolution is focusing on fixing and solving problems. There are some well-known approaches for the problem-solving purposes, such as Plan-Do-Check-Act (PDCA) of Deming, Seven Steps of Juran and Gyrna, and DMAIC for Six Sigma (de Mast and Lokkerbol, 2012). The latter one is an instrument of Six Sigma which stands for Define-Measure-Analyse-Improve-Control. It promises an improvement procedure and gives an effective contribution to quality management. As a non-linear process, each early step can be re-evaluated once new information is obtained (Stamatis, 2004). On its development, this approach is widely used in manufacturing aspect. Kumar and Sosnoski (2009) proved that DMAIC methodology is powerful to improve product quality as well as reducing cost in the manufacturing sector. By highlighting the generic activities of each phase, this quality management implementation can be adapted to other aspects of the organisation to assist problem-solving. The overview of DMAIC for Six Sigma is shown in Table 5-3.

Table 5-3 Phases of DMAIC for Six Sigma, adapted from Koning and Mast (2006), Stamatis (2004) and Kumar and Sosnoski (2009)

Phase	Generic Activities	Example of Tools
Define	Determination of role and responsibility of each team member, problem selection, and benefit analysis	Voice of Customer, Data Collection, Survey, Focus Group, Pareto chart
Measure	Translation of the problem into a measurable form, and measurement of the current situation	Pareto chart, FMEA, Control chart
Analyse	Analysis of the preliminary data and identification of influence factors and causes that determine the Critical-To-Qualities' (CTQs') behaviour	Brainstorming, Fishbone diagram, Data mining
Improve	Design and implementation of adjustments to the process to improve the performance of the CTQs	ANOVA, Benchmarking, Experimental Design, Brainstorming
Control	Adjustment of the process management and control system in order that improvements are sustainable	Statistical Process Control, Checklist

As a generic activity, each phase may be treated with a slightly different task to get it fit with particular cases in a frame of problem resolution orientation. Many papers show that many different tools might be used, even more than once on a different phase to develop a proper and clear circumstance of each phase (Stamatis, 2004; Koning and Mast, 2006). Furthermore, in the KBIMSO framework, DMAIC is adapted to be used in assisting implementation of developed the KBIMSO framework for problem resolution.

5.6.2 Problem Prevention through DCOV

Different from problem resolution which is employed to fix the problem, problem prevention is a proactive approach intended to avoid potential problems. For this need, Six Sigma offers a modern approach called Design for Six Sigma (DFSS) (Gremyr and Fouquet, 2012). It uses a method called DCOV, which stands for Define-Characterise-Organise-Verify. Although it is less popular than DMAIC, DCOV focuses on preventing problems (Stamatis, 2004) in developing a new product and service. The overview of DCOV is shown in Table 5-4.

Table 5-4 Phases of DCOV for Six Sigma, adapted from Stamatis (2004)

Phase	Generic Activities	Example of Tools
Define	Identification of the Critical-To-Satisfaction (CTS) drivers and related factors contributed to the drivers.	Kano model, Quality Function Deployment (QFD)
Characterise	System design and functional mapping	Functional structures, Axiomatic design
Organise	Design for robust performance and design for productivity	Experimental Design, FMEA
Verify	Assessment, test and verify the capability and integrity of the proposed system	Reliability method, design reviews

Implementation of Six Sigma widely spread not only at a specific project or department but also at the corporate level (Tjahjono et al., 2010). Thus, DMAIC and DCOV are also possible to be used for developing system improvement such as this KBIMSO framework.

However, the matter of time required and management commitment become the issues that cause this last stage of KBIMSO could not be conducted. For this reason, the ability of KBIMSO to support maintenance decision making is confirmed through the validation and verification of the KBIMSO model.

5.7 Conceptual Framework of the KBIMSO

All important aspects on every stage are structured in a KBIMSO framework, as can be seen in Figure 5-19. The knowledge base contains sources of knowledge which are required to develop each stage. Eventually, it will be used to analyse all variables simultaneously based on hybrid KB System/GAP/AHP methodologies to support maintenance decision making.

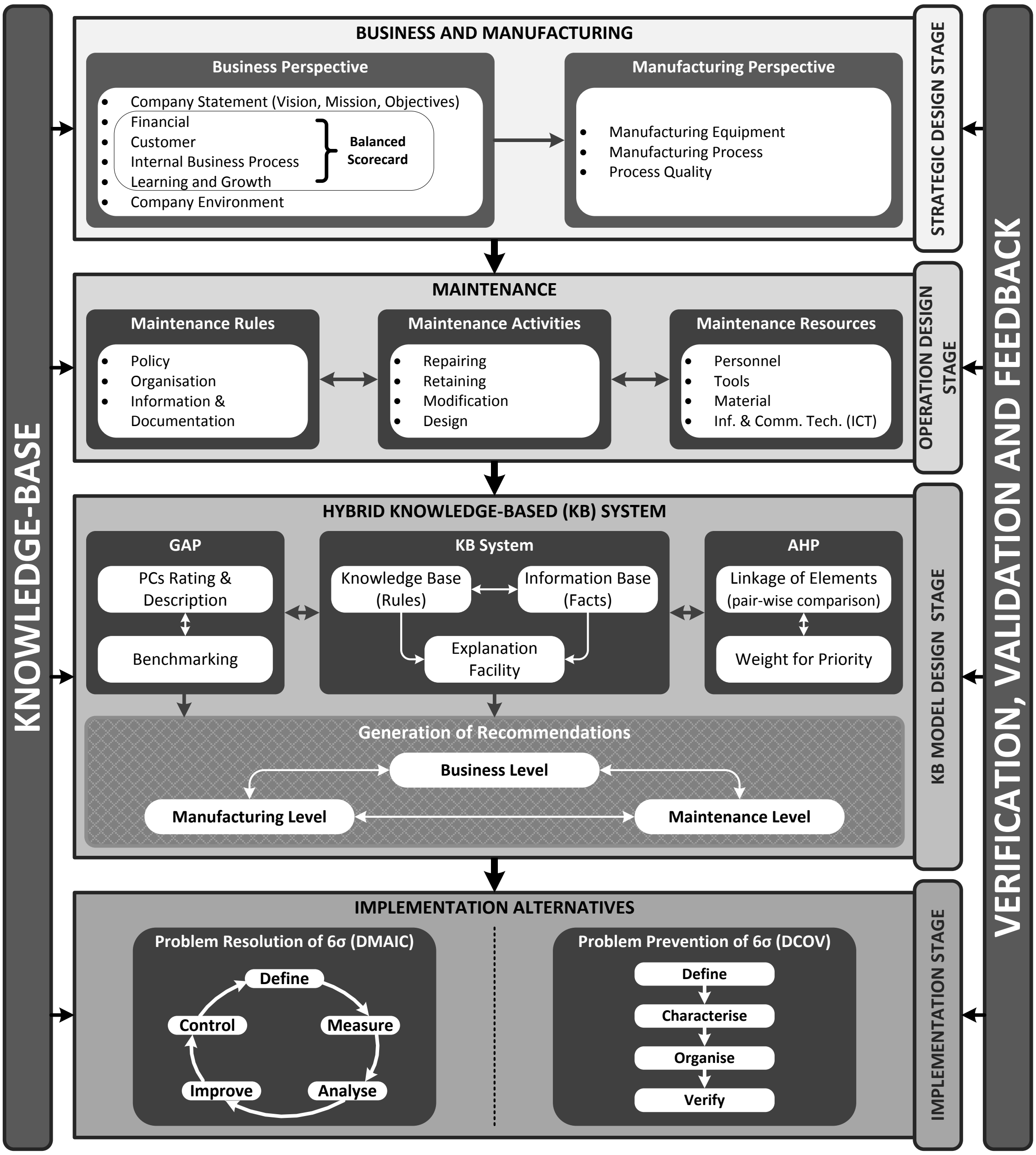


Figure 5-19 Conceptual framework of the KBIMSO

On the next step, the developed KBIMSO framework is explored to develop a KBIMSO model. The KBIMSO model is then verified and validated practically and academically through industrial and published case studies. All feedback gained from these processes are deployed to refine and improve the KBIMSO model as a continuous improvement process, thus it could be implemented and beneficial to support maintenance decision making.

5.8 Structure of the KBIMSO Model

The development of the KBIMSO model within automotive industry environment emphasises the first three steps of the KBIMSO framework; *Strategic Design Stage*, *Operation Design Stage*, and *KB Model Design Stage*, as can be referred again to Figure 5-19. Every single element of business perspective, manufacturing perspective and maintenance perspective is treated as a module and is explored in detail into sub-modules to present the key factors and knowledge rules contributing to KBIMSO. The *Strategic Design Stage* in the KBIMSO framework is explored on the *Strategic Stage* in the KBIMSO model, whilst the *Operation Design Stage* in the KBIMSO framework corresponds to the *Maintenance Operations Stage* in the KBIMSO model. The *KB Model Design Stage* in the KBIMSO framework works as the tool to support KBIMSO to reach maintenance recommendation. Furthermore, the main aspects of business, manufacturing and maintenance perspectives on the KBIMSO framework are explored to generate KB rules on KBIMSO model, with the structure presented in Figure 5-20. Each sub-module from Level 1 to Level 5 is analysed through GAP analysis and weighted through AHP analysis as the way to provide a recommendation based on prioritisation.

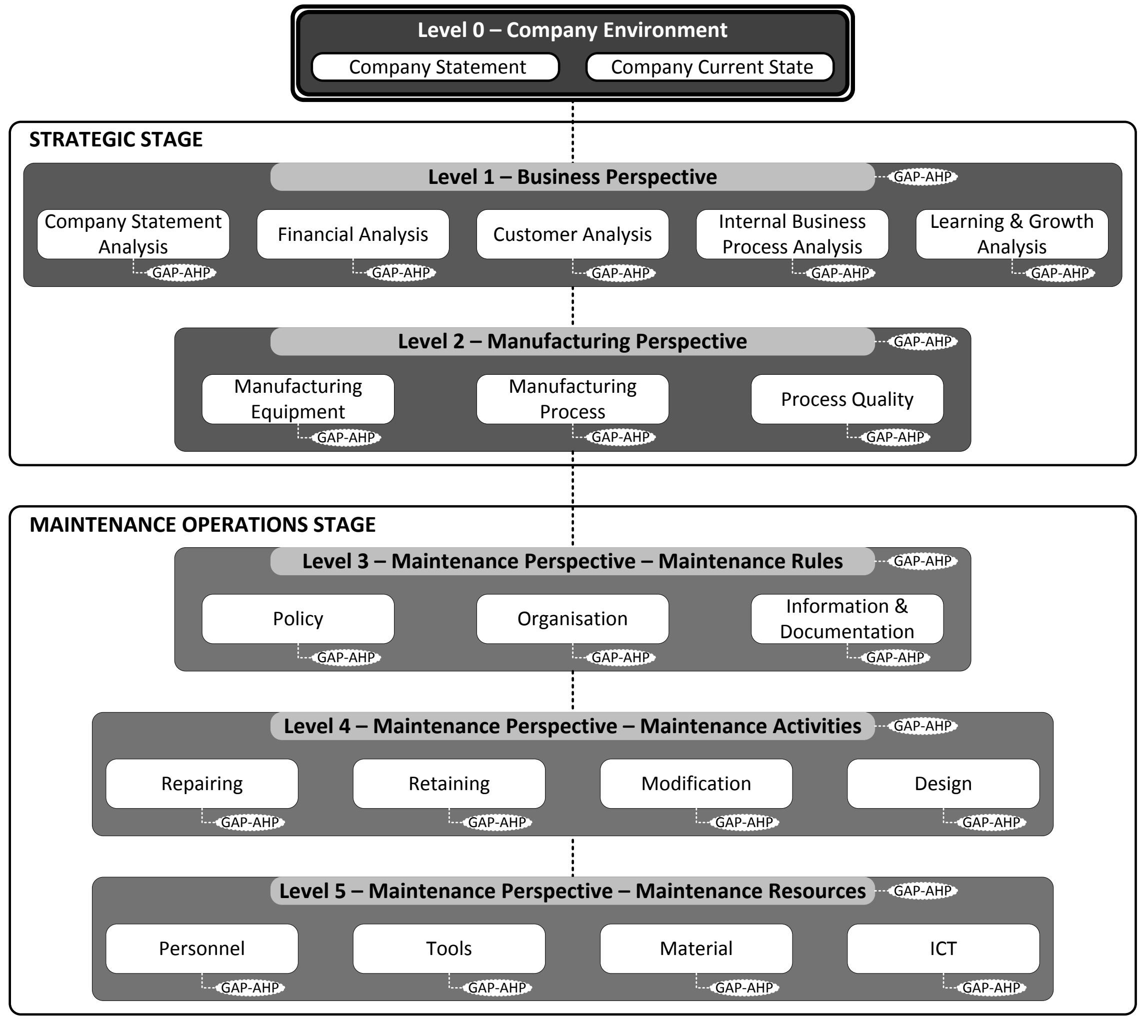


Figure 5-20 Structure of the KBIMSO model

5.9 Supporting Techniques and Methods for the Development of the KBIMSO

With the significant evolution of computer and data processing techniques, rapid and accurate decision making is possible to be handled and repeated. As a branch of Artificial Intelligent (AI), Knowledge-Based (KB)/Expert System(ES), hereinafter referred to as Knowledge-Based Systems, work intelligently like human beings in recommending advice based upon the input problem (Liao, 2005). The application of a KB System lies widely in the area of medical, environmental, engineering, and agricultural, to name but a few. Therefore, its ability to support decision making is reliable. The KB Systems not only enable dealing with rapid decision making but also ensure valid and consistent logical background for its recommendation (Milana et al., 2017). Besides being a decision making technique, it is also a benchmarking technique to compare the existing system and its ideal condition. To analyse the gap between these two for achieving an optimal implementation, the Gauging Absence of Pre-requisites analysis is integrated into the KB systems (Khan and Hafiz, 1999; Udin et al., 2006a). The approach of KB Systems with GAP and AHP will empower the development of an integrated maintenance strategy and operations which has not been carried out in the past.

5.9.1 Elements of KB System for the KBIMSO

The development of a KB System is facilitated through a KB shell thus the initial process is not started from inception (Awad, 1996). The KB shell already has contents for supporting of defining and structuring the KB rules that have been generated.

The development of the KBIMSO model in this research is supported by software called Application Manager (AM) which is developed by Intelligent Environments Inc. Its visual interactive interface, as well as database access and remote system connectivity, enable the development of client/server application (Intelligent Environments, 1995). To support the application development, AM is equipped with objects of *module*, *procedures*, *commands*, *variables*, *windows*, *functions* and *menus*. Those AM objects contribute to design and develop the KBIMSO application such as structuring the rules, developing the logic formula, creating the inferences, storing the information and retrieving the information.

With the support of those AM objects, the KBIMSO presents the *User Interface Facility* to help the users interact comfortably with the system in order to obtain the correct information. This interface facility also covers two supporting functions called *Answer Facility* and *Explanation Facility*.

5.9.1.1 User Interface Facility

The user interface is known as the communication facility between the user and the KBIMSO application. It acts as the basic need to gain input for the KBIMSO. It could be presented through a simple text-oriented display or a high-resolution display integrated with control panel (Giarratano and Riley, 2005). By using AM software in developing the KBIMSO model, the user interface is facilitated through the *Display Windows* tool. The appearance of the question, the answer options, and the explanatory facility is shown on the provided screen with respect to the user-friendly application. Each question and its answer space will be always placed on the same screen page. However, the explanation for such questions will be displayed on the additional page. It will appear when the user requests it by clicking the explanation button. Thus, the explanatory facility acts as the complement for the question for which it will be opened when the user is not definitely clear about the statement of the question and what is the question intended for.

5.9.1.2 Answer Facility

This facility is the entrance for the user to give input into the KBIMSO model to make a correct decision. The *Answer Facility* is developed in the form of closed answer. It means some options of answer are already provided for the user to choose. The closed answer option is considered as the better way to direct the user for providing the correct input into the KBIMSO model. Practically, the question is followed by some options of answer. It might appear on a range of intensity such as very important to very unimportant or might appear on options to choose the best relevant condition or practice. In case the question is intended for GAP analysis, the importance of such statement of the answer will be followed by the scale of Problem Category.

5.9.1.3 Explanatory Facility

The question provided in the KBIMSO attempts to minimise ambiguity through the *Explanatory Facility* to avoid misperception for the users to answer. Hence, further knowledge is actually embedded in the *Explanatory Facility*. But still, the interpretation of users to the given questions might vary influenced by their level of understanding and familiarity with the term used, knowledge, and experience. It likely raises deviation on the response and directs the users to choose the wrong answer. In turn, it will influence the validity of result and recommended priorities for maintenance decision making. For this reason, avoiding bias and misunderstanding through *Explanatory Facility* is considered as a necessary part embedded into the KBIMSO model.

Explanatory Facility contains the additional information and knowledge to assist the users obtaining the correct perception towards the issues presented. It consists of simple and easily understood but standardized definitions and statements which assist the users to understand the given question. It might also appear to indicate the recommended good practices which need to be implemented within the organisation (Wibisono, 2003; Nawawi, 2009). Hence, in this research, Bayesian, probability and fuzzy logic methods are not used to cover uncertainty issues for the KB system, but every question has a detailed *Explanatory Facility* to assist the user to overcome the uncertainty.

5.9.2 Gauging Absences of Pre-requisites for the KBIMSO

The input for Gauging Absences of Pre-requisites analysis is collected from the feedback of the users regarding the questionnaire based on KB rules in the KBIMSO application. Good Point (GP) refers to the achievement of performance to meet its standard and Bad Point (BP) refers to the identified problem. To gain an optimal analysis of benchmarking process, GAP is designed systematically. The severity of problems and its impact on system sustainability are treated to stipulate the level of the problem so-called Problem Category (PC). The absence of any pre-requisite condition is described hierarchically from the most important one to the system sustainability to the less important of which it does not have any effect on the system at all. By modifying the GAP analysis described by Mohamed and Khan (2012), the description of each PC for the KBIMSO is presented in Table 5-5.

The most urgent problem to be solved immediately is coded as PC-1. It is a very serious problem which influences process continuity. Resolving this problem is strongly required immediately. Otherwise, the last PC so-called PC-9 is addressed to the problem that does not need to be fixed. It is a kind of problem that might not have an impact at all to the system, thus waste efforts to fix it (Stamatis, 2004). However, this PC could indicate a current situation of the system. The rest of PCs lie in the range of PC-1 and PC-9, based on their intensity of severity, their role as pre-requisite for another element or process, and their benefit to the system.

Table 5-5 Problem Categories (PCs) and description of GAP analysis technique for the KBIMSO

Category	Description
PC-1	**This indicates a significant problem**, which involves pre-requisites to the system and may impact overall system performance in a short period of time. It should and can be resolved in a short-term and through appropriate and logical improvement and implementation plan. The solution of the problem is likely to provide a real short-term benefit.
PC-2	**This indicates a serious problem**, which involves pre-requisites to the system and may impact overall system performance after a period of time. It should and can be resolved in a short-term and through appropriate and logical improvement and implementation plan. The solution of the problem is likely to provide a real short-term benefit.
PC-3	**This indicates quite a major problem**, which is most likely to have pre-requisites to the system and may impact overall system performance after a period of time. It is better dealt with as part of an appropriate and logical improvement and implementation plan. The solution of the problem is likely to provide a real short-term benefit.
PC-4	**This indicates a major problem**, which is likely to have pre-requisites to the sub-system and is better dealt with as part of an appropriate and logical improvement and implementation plan. The solution of the problem is likely to provide a real short-term benefit.
PC-5	**This indicates a moderate problem**, which is likely to have pre-requisites to the sub-system. It can be dealt immediately without an appropriate and logical improvement and implementation plan. The solution of the problem is likely to provide short-term benefits.
PC-6	**This indicates a minor problem**, which is likely to have pre-requisites to minor activities in the sub-system. It can be dealt immediately without an appropriate and logical improvement and implementation plan. The solution of the problem might provide short-term benefits.
PC-7	**This is not a serious problem**. Although it could be dealt immediately, it is unlikely to produce short-term benefit. Therefore, it should only be dealt with if it is a pre-requisite for other things.
PC-8	**This is not really a problem**. However, it is important to consider certain situations as a future improvement.
PC-9	**This is not really a good or bad point itself**. The questions associated with this category are primarily asked to identify certain situations in the environment, which upon subsequent probing by succeeding questions; may well reveal problems.

5.9.3 Analytic Hierarchy Process for the KBIMSO

The problem in maintenance is usually derived from the unavailability of neither clear criteria nor robust decision in maintaining failing equipment (Labib et al., 1998). To make a strong decision, there are many variables that should be put into consideration at one time. According to its complexity, it definitely requires a multi-criteria decision making method to consider various parameters. For this purpose, the application of Analytic Hierarchy Process appears to deal with this challenge. It has been known widely as a simple but powerful method to do a pair-wise comparison and putting the weight of criteria for making decisions.

The effective implementation of AHP in the KBIMSO requires the systematic procedures as the following:

a. Specifying the problem

   The problem to be solved in this research with the assistance of AHP is to decide the priority of improvement in the Integrated Maintenance Strategy and Operations. The elements contributing to the KBIMSO are generated from business, manufacturing and maintenance perspectives. Once the problems are identified through GAP analysis, it is weighted by AHP to decide the priority of improvement.

b. Structuring the decision hierarchy and linking the goal, criteria and sub-criteria

   The goal is situated on the top level, followed by some criteria on the next levels. The structure of AHP for the KBIMSO model is illustrated in Figure 5-21.

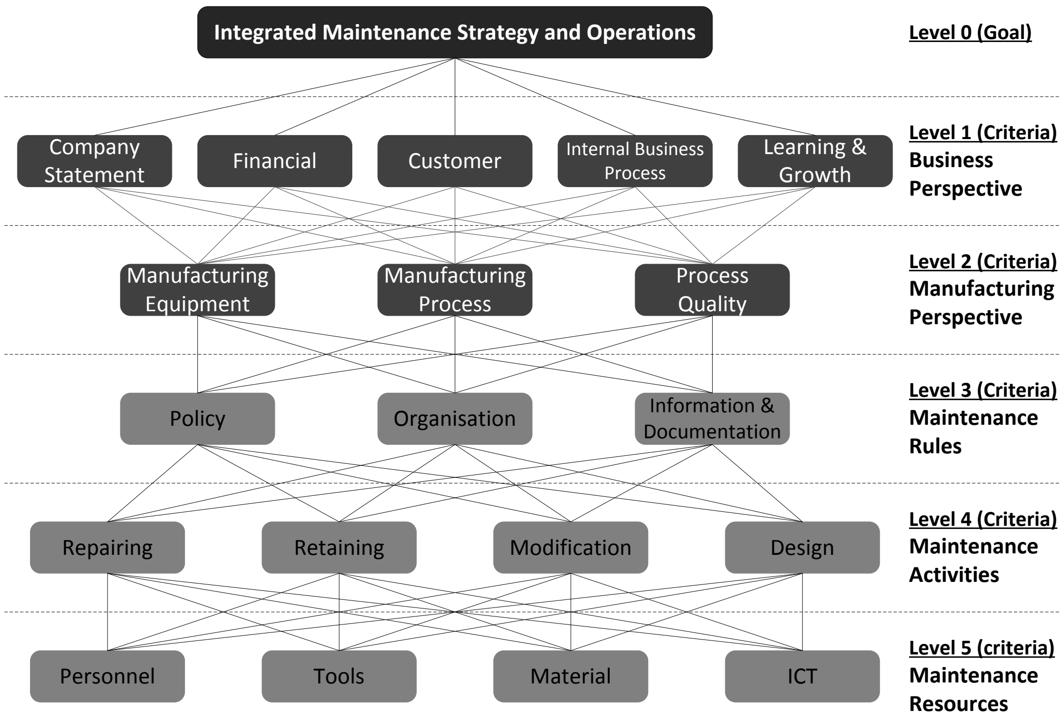


Figure 5-21 AHP structure for the KBIMSO

Level 0 is intended to state the goal to be achieved through the AHP in the KBIMSO. *Level 1* to *Level 5* mentioned the criteria used to reach the goal. In *Level 1 – Business Perspective*, there are five criteria identified which are *Company Statement, Financial*, *Customer*, *Internal Process Business* and *Learning and Growth*. These criteria link to criteria in *Level 2 – Manufacturing Perspective*. Those are *Manufacturing Equipment*, *Manufacturing Process*, and *Process Quality*. These upper criteria are connected to the next criteria on *Maintenance Perspectives*, which are *Level 3 – Maintenance Rules*, *Level 4 – Maintenance Activities* and *Level 5 – Maintenance Resources*. Each of criteria contains certain sub-criteria which are linked together to upper and lower levels.

c. Construct the pair-wise comparison matrix

This pair-wise comparison compares the element on the upper level with the element at the lower level. As the KBIMSO involves manufacturing and business perspectives as the basis for making maintenance decision, the pair-wise comparison of AHP is started from the *Level 1 – Business Perspective*. This means that *Level 1* and *Level 2* in this KBIMSO have the contribution to provide descriptions of the existing system in the company and to assign the priority of improvement for the KBIMSO.

In the KBIMSO, each element will be assessed through the user's responses on a set of question. The answer is then classified into Good Point (GP) or Bad Point (BP). The BP is distinguished into some problem categories based on the level of importance and severity effect of such elements into the system, as can be referred to Table 5-5. Therefore, the comparison in the AHP is intended to compare the level of importance and severity of each PC to others in a pair-wise manner. The complete comparison of this process can be seen in Table 5-6.

Table 5-6 Pair-wise comparison matrix of Problem Categories for the KBIMSO

	PC-1	PC-2	PC-3	PC-4	PC-5	PC-6	PC-7	PC-8	PC-9
PC-1	1	2	3	4	5	6	7	8	9
PC-2	1/2	1	3/2	2	5/2	3	7/2	4	9/2
PC-3	1/3	2/3	1	4/3	5/3	2	7/3	8/3	3
PC-4	1/4	1/2	3/4	1	5/4	3/2	7/4	2	9/4
PC-5	1/5	2/5	3/5	4/5	1	6/5	7/5	8/5	9/5
PC-6	1/6	1/3	1/2	2/3	5/6	1	7/6	4/3	3/2
PC-7	1/7	2/7	3/7	4/7	5/7	6/7	1	8/7	9/7
PC-8	1/8	1/4	3/8	1/2	5/8	3/4	7/8	1	9/8
PC-9	1/9	2/9	1/3	4/9	5/9	2/3	7/9	8/9	1

Initially, PC-1 on the left is compared to PC-2 on the top to identify how important is PC-1 to PC-2. Then, PC-1 on the left is compared to PC-3 until PC-9 on the top. The next step is continued to compare PC-2 on the left to PC-3 until PC-9 on the top. This process is repeated to reach the comparison between PC-8 on the left and PC-9 on the top. By referring to Table 5-5 about Problem Category and description of GAP analysis, it can be seen that the classification of each PC of GAP analysis has been arranged proportionally to sort each milestone of problem and severity impact of each category to the system. Thus, to scale the importance of PC-1 towards PC-2, the assumption is made that the PC-1 is two times more important than PC-2, three times more important than PC-3, four times more important than PC-4, and so on of which it is nine times more important than PC-9. Since these scales of number are put horizontally on PC-1 row, the reciprocal value is sorted vertically on PC-1 column as ½, 1/3, ¼, and so on until 1/9, respectively. Following this rules, the reciprocal value of comparison between PC-2 and other PCs is filled vertically on PC-2 column. At the end of the pair-wise comparison process, the scale of comparison of PC-8 with PC-9 has already being filled in PC-8 row and the reciprocal value has been put in PC-8 column.

d. Weight the problem categories

By referring to the pair-wise comparison result, the weight of each PC can be obtained, as shown in Table 5-7. The highest scale is 9 for PC-1, and the lowest scale is 1 for PC-9. The consecutive scales which lie on the PCs show the consistency of weighting with the level of importance of Problem Categories. PC-1 indicates the very serious problem which needs to be solved immediately. Otherwise, PC-9 indicates the less serious problem that does not refer to a specific issue.

Table 5-7 Weighting scale of Problem Categories for the KBIMSO

Problem Category	Weight
PC-1	9
PC-2	4.5
PC-3	3
PC-4	2.25
PC-5	1.8
PC-6	1.5
PC-7	1.29
PC-8	1.13
PC-9	1

e. Assign each component to the Intensity of Importance

This process is formed in the matrices by referring to Table 4-1. The forming of the preference matrices are intended to obtain priority on each level of criteria or sub-criteria.

f. Ensure the consistency of priority

The inconsistency of priority due to subjective preferences on the pair-wise comparison is likely to happen. However, it is important to ensure that the inconsistency is acceptable. Therefore, the *Consistency Ratio* (CR) is measured by comparing the consistency index of the dedicated matrix on KBIMSO modules/sub-modules, which is called CI, versus the consistency index of a random-like matrix, which is called RI, by following the Equation (4) below:

$$CR = \frac{CI}{RI} \qquad \text{Equation (4)}$$

RI is an average random consistency index obtained from a large number of simulation runs (around 500 random CI) and varies depending upon the order matrix (Ilangkumaran and Kumanan, 2009). The RI values for different sizes of matrices used on this research are taken from simulation run by Saaty (Saaty and Vargas, 2001) as shown in Table 5-8.

Table 5-8 Average random consistency index (Saaty and Vargas, 2001)

N	1	2	3	4	5	6	7	8
RI	0	0	0.52	0.89	1.11	1.25	1.35	1.41

In fact, the RI values from a similar large number of simulation runs conducted by Alonso – Lamata shows no significant different from the RI values produced by Saaty (Alonso and Lamata, 2006).

CI can be found by calculating λ_{max} in the Equation (5) below:

$$CI = \frac{\lambda_{max} - n}{n-1} \qquad \text{Equation (5)}$$

where λ_{max} is the largest eigen factor in the matrix (Aguilar-Lasserrea et al., 2009) and n is matrix size.

The CR value that is bigger than 0.10 means that there is more than 10% possibility that the elements have not been compared properly. This condition requires the decision maker to review the comparison again until the CR value less or equal to 0.10.

Although a large number of studies have proven that AHP plays a satisfying method to tackle multi-criteria problems, it is considered that the calculation might be tedious in practice. The dynamic nature of rapid knowledge and information change is another issue. Spinosa and Dos Santos Coelho (2008) proposed the soft computing approach and intelligent agent-oriented design as a potential solution. They specify the implementations of artificial intelligence, fuzzy system, and evolutionary computation. In line with this statement, Razmi et al (1998) emphasized that integration of AHP to an expert system to make it simple and accurate to apply. For this reason, the collaboration of GAP and AHP in KB system will firmly provide the valid and consistent recommendation.

5.10 Chapter Summary

This chapter has presented the detailed explanation of the design and development of the novel KBIMSO framework linked to manufacturing and business perspectives. This KBIMSO framework consists of four main stages, which are *Strategic Design Stage*, *Operation Design Stage*, *KB Model Design*

Stage, and *Implementation Stage*. The Knowledge Base is fundamental and the key to the KBIMSO framework to perform at every stage. Furthermore, verification and validation feedback keeps the evaluation process of each stage is under control.

The *Strategic Stage* consists of manufacturing and business perspectives. On business perspective, Balanced Scorecard approach is employed to identify the current position of the company through four BSC perspectives which present company's strategy related to maintenance function. Meanwhile, manufacturing perspective is counted on some critical elements which have high relationship and demand to maintenance.

The *Operation Design Stage* acts as the core of this KBIMSO framework. It consists of three elements of maintenance in a frame of maintenance system; those are maintenance rules, maintenance activities, and maintenance resources. These elements will then be connected and compared in order to make recommendation in a priority manner to achieve optimal maintenance performance.

All this information is then integrated into the *KB Model Design Stage*. It embeds AHP and GAP to KB system to assist benchmark and prioritisation in decision making process. In the KB system, a significant number of KB rules will be generated and structured to determine the circumstance of the current system and its drawbacks, so that the improvement decision can be proposed.

The last stage of the KBIMSO is the *Implementation Stage*. It offers two approaches to assist system development, by respecting to specific needs of a particular problem. DMAIC approach is intended to deal with problem resolution by identifying and fixing the problem. Meanwhile, DCOV is employed to deal with problem prevention which avoids the problem to happen.

The conceptual framework of the KBIMSO is then designed and developed as a representation of the holistic ideas and structure of the KBIMSO. The detailed development process of all perspectives and elements of the KBIMSO is discussed in Chapter 6 and 7.

CHAPTER 6

Developing the Strategic Stage of KBIMSO

6.1 Introduction

The design of KBIMSO model consists of generating the structure of KBIMSO, identifying the necessary techniques to develop KBIMSO, and identifying the characteristic of the automotive company where KBIMSO will be applied. The transformation of KBIMSO conceptual framework into KBIMSO model by generating the structure of KBIMSO is discussed within two chapters. This chapter emphasises the *Strategic Stage* of KBIMSO. Referring again to KBIMSO structure in Figure 5-20, the particular KBIMSO structure of *Strategic Stage* is presented in Figure 6-1.

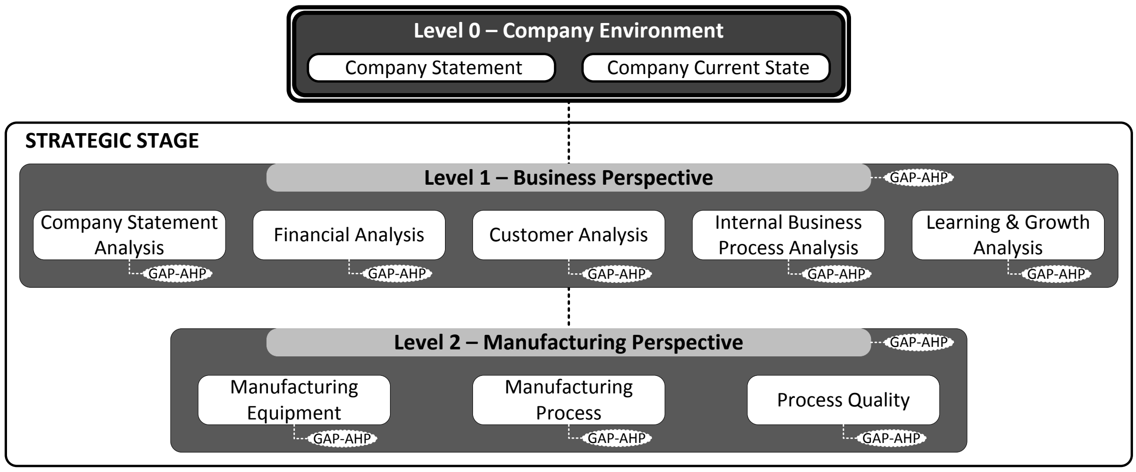


Figure 6-1 Particular structure of the KBIMSO model - Strategic Stage

This chapter details the design of KBIMSO model from the identification stage of company environment, the so-called *Level 0*. This level encompasses the representation of an automotive company to face business competition through company statement as well as the company current state which identifies the current condition of the organisation. After that, Level 1 and Level 2 are then discussed. Level 1 encompasses aspects of business while Level 2 encompasses aspects of manufacturing that influence maintenance performance. Along with that, the techniques used to support the development of the KBIMSO model are introduced. The flowchart of *Strategic Stage* is presented in Figure 6-2.

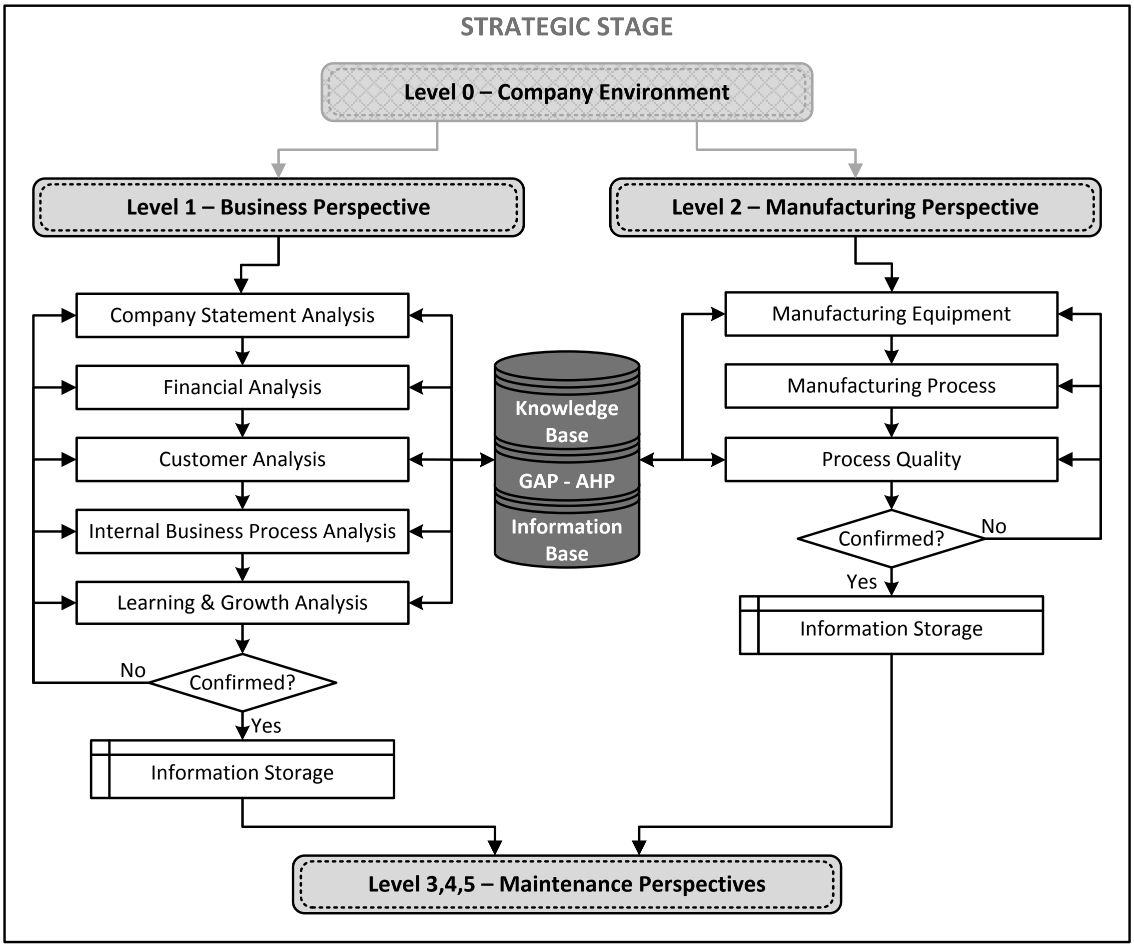


Figure 6-2 Flowchart of Strategic Stage

6.2 Level 0 – Company Environment

Level 0 – Company Environment is the top level of KBIMSO model which is intended to describe the automotive company environment through identifying company statement and company current state. The detailed structure of Level 0 is shown in Figure 6-3.

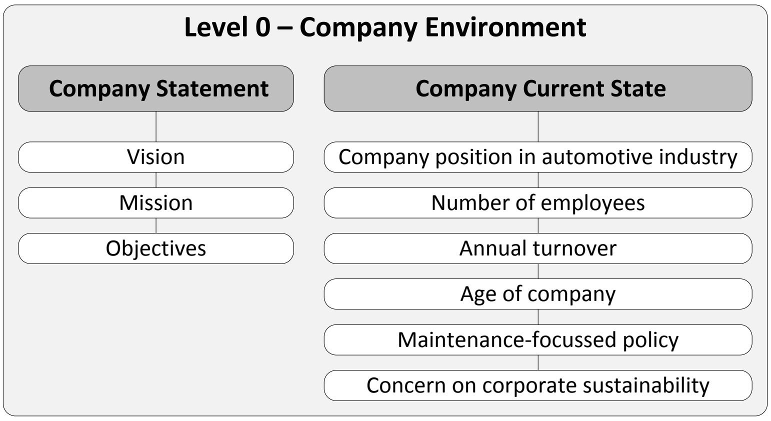


Figure 6-3 Detailed structure of Level 0 – Company Environment

Company statement includes vision, mission, and objectives of the company to compete in the automotive industry. The company statement is required to generate the suitable strategy and operations for the lower level of functions. To accommodate the speciality of the company, it is important to consider the current state in which the company is running. The point of this identification process is to consider each company as a unique system and to classify any particular company into different characteristic to arrange the suitable requirement for the development of the KBIMSO model. The process flowchart for *Level 0 – Company Environment* is shown in Figure 6-4. On this level, the KB rules are started to be generated.

KB rules, as the collection of facts, are considered as the data. This data is then combined systematically to develop information within a KB system approach (in term of IF…THEN… pattern). With the integration of KB system with GAP and AHP analysis, the information can be used to propose recommendation of priority. This recommendation is then counted as knowledge. The know-how leads KBIMSO in identifying the most problematic problems which should be tackled to improve maintenance performance. KB rules ideally include all sort of requirements for a particular performance can be achieved, from the most important and compulsory ones to the less important ones but needed to be investigated to figure out the whole picture of the system.

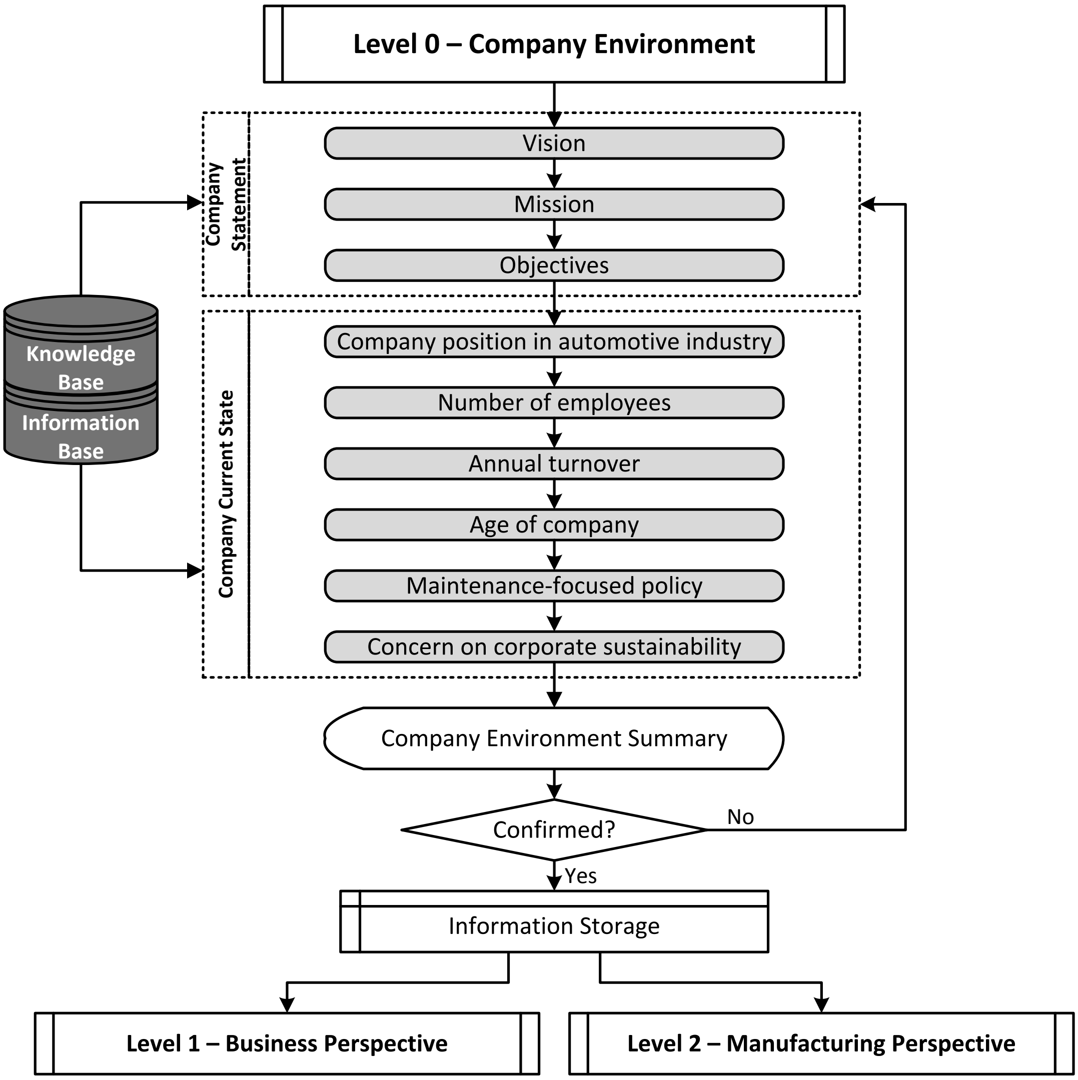


Figure 6-4 Flowchart of Level 0 – Company Environment Module

To support the translation process of company statement (in the form of vision and mission) to strategic and operational level, the characteristic of each company should be recognised and accommodated. For this reason, the specific description about the current state of the company needs to be clear. Since the KBIMSO model is verified in the automotive industry, it is important to identify the product of such automotive industry, size of the company, number of employees, annual turnover, age of the company, number of suppliers, maintenance focused activities, and its concern on global issues of social and environment.

Each point has a set of KB rules which are designed and developed through some questions for the users to respond. To answer the questions, the user refers to available information and documentation within the company. The answers are stored and then processed to determine the classification of the company. As a brief example, the developed rules of a KB system to clarify company statement are presented below:

IF *the company has the vision statement*
AND *the company has the mission statement*
AND *the company has the objectives to reach its vision and mission statements*
THEN *the company already has a comprehensive company statement*
OR *the company still needs to complete its company statement*

This information will be used as the references for the next step. To classify the company based on sized, the KB rules are developed and generated as the following:

IF *the company has less than 10 employees*
AND *the company has annual turnover less than or equal to € 2 million*
THEN *the company is classified as a micro company*
OR *the company has less than 50 employees*
AND *the company has annual turnover less than or equal to € 10 million*
THEN *the company is classified as a small company*
OR *the company has less than 250 employees*
AND *the company has annual turnover less than or equal to € 50 million*
THEN *the company is classified as a medium company*
OR *the company is classified as a large company*

In *Level 0 – Company Environment*, the GAP technique has not been embedded because this level is only intended to provide the general description of the company. However, since business perspective is an important part to develop the KBIMSO, some information gained will be investigated deeply in the next levels, especially the company's commitment on spreading and socialising vision and mission to the entire organisation, maintenance-focused policy, and the company's concern on global issues of social and environment.

6.3 Level 1 – Business Perspective

The *Strategic Stage* concerns with manufacturing and business perspectives that contribute toward the development of the KBIMSO model, namely *Level 1 – Business Perspective* and *Level 2 – Manufacturing Perspective*, respectively. The detailed structure of Level 1 is shown in Figure 6-5.

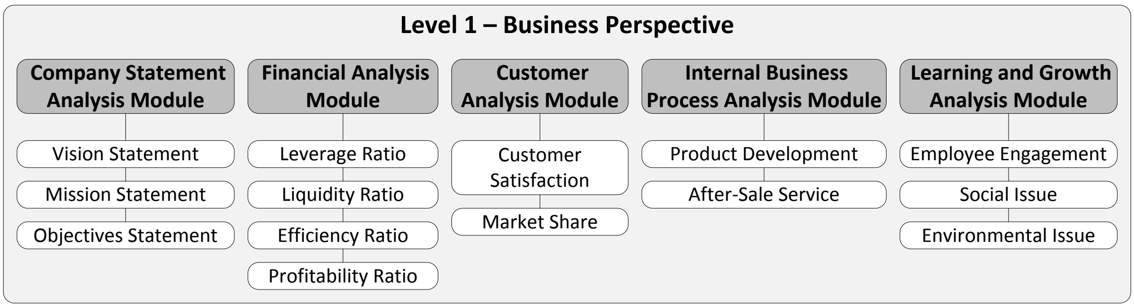


Figure 6-5 Detailed structure of Level 1 – Business Perspective

As mentioned in the previous chapter, the business perspective adopts BSC approach to provide an overall business performance measurement through four perspectives, financial, customer, internal business process, and learning and growth. These four perspectives are able to effectively represent existing business performance and help to identify the prospective achievement in the future (Kaplan and Norton, 2007). These perspectives of BSC are represented through modules in *Level 1 – Business Perspective* of the KBIMSO model. Additionally, the *Company Statement Analysis* is included to emphasize the role of company statement as the guideline to achieve organisation goal. The process flowchart of *Level 1 – Business Perspective* of the KBIMSO is shown in Figure 6-6.

The discussion in *Level 1 – Business Perspective* is started with *Company Statement Analysis Module*. It has two sub-modules, *Value Socialisation Sub-Module* and *Value Integration Sub-Module*. Each sub-module consists of generated KB rules while each KB rule is embedded with GAP analysis. In *Company Statement Analysis Module*, these two sub-modules are compared in a pair-wise manner as part of AHP analysis to get priority of recommendation to improve the role of company statement. Then, all modules within *Level 1* are also compared in a pair-wise manner as part of AHP analysis to get priority of recommendation to improve the role of business perspective. Once the AHP recommendation for *Level 1* is obtained, the KBIMSO process is continued to *Level 2*.

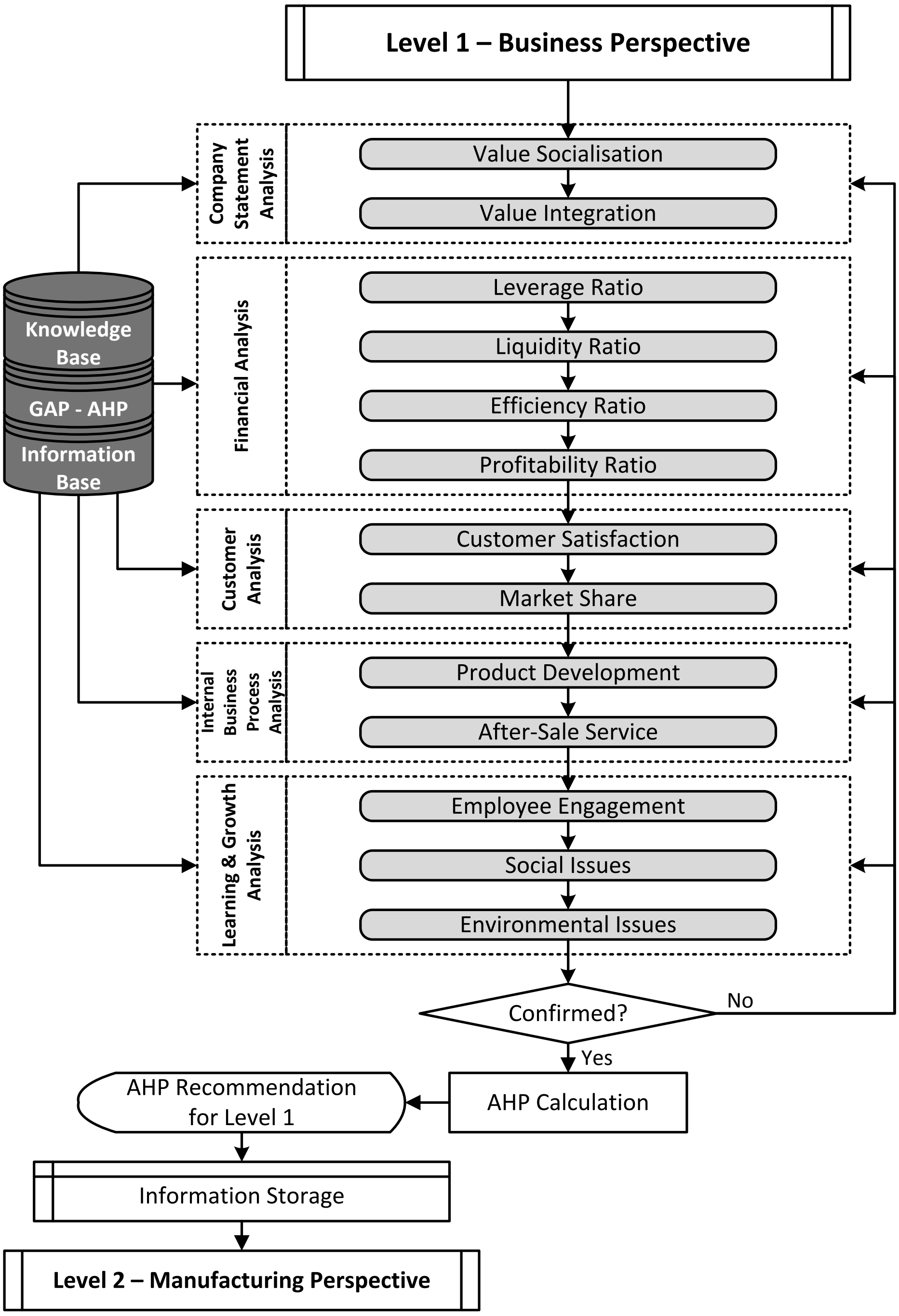


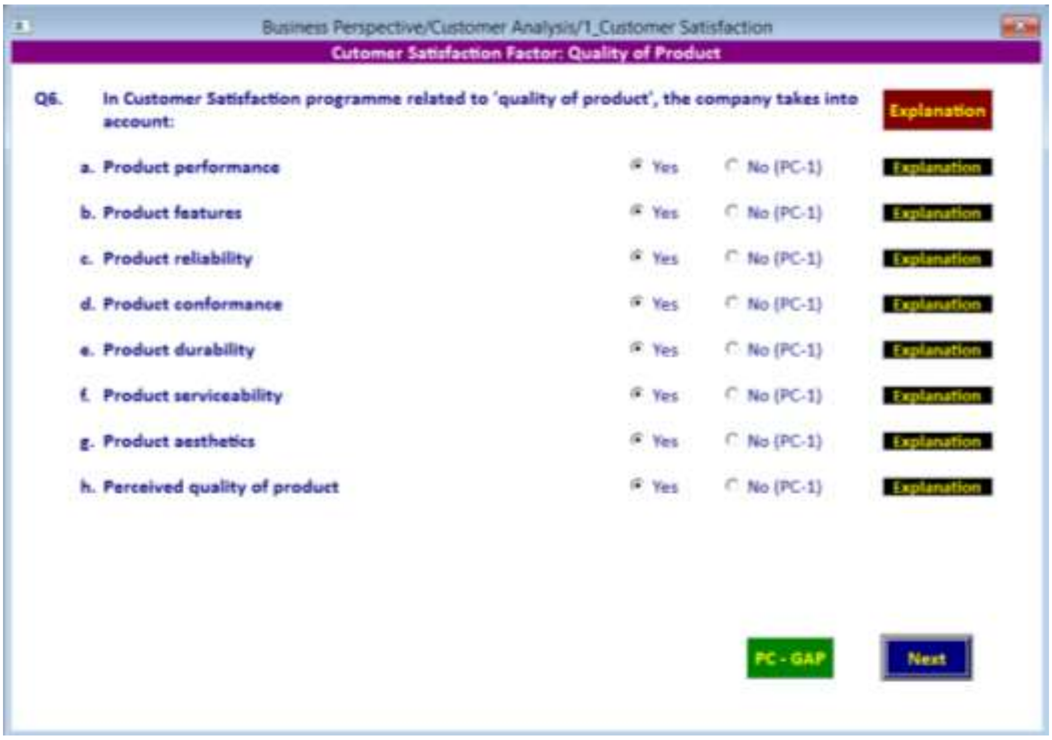
Figure 6-6 Flowchart of Level 1 – Business Perspective

Referring to the explanation of supporting method to develop the KBIMSO in Section 5.9, the transformation of the KBIMSO framework into the KBIMSO model and then into KBIMSO application is initiated through generating and structuring the KB rules for each module and sub-modules of the KBIMSO. The list of KB rules is structured in the form of queries for the user regarding the existing condition within the company. The GAP analysis is embedded into each KB rule to indicate the gap effect between the current system and pre-requisite condition. To ensure the accuracy of appointed PC on each KB rule, the literature review, as well as the discussion with academic and industry experts, are managed during the generation of all KB rules.

Furthermore, the AHP analysis is integrated into the KBIMSO model to compare all sub-modules under a module and to compare all modules under a level in a pair-wise manner in order to set the priority of recommendation based on GAP analysis. With the support of AM software, KBIMSO application is developed to ease the users in responding KB rules of KBIMSO model, to present the summary of GAP analysis, and to support AHP analysis procedures to obtained valid and consistent result.

The implementation of KBIMSO model is presented through KBIMSO application. To response the KB rules, the users are provided with the question pages. Each module in KBIMSO application is started with the guidelines that explain the *Objectives*, *Reasons*, and *Variables to be assessed* in such module before it comes with the questions based on the KB rules. One or more questions are presented on each page based on certain aspect discussed within sub-modules and modules. The illustrations of questions to be responded by the users within KBIMSO application are shown in Figure 6-7. The buttons to access Explanation page and PC-GAP page (description of GAP analysis) are always provided on each page.

Referring to Figure 6-7 (a) and (b), the question pages are differentiated into two kinds of responses. Figure 6-7 (a) shows the question with two options, *Yes* which means Good Point, or *No* which means Bad Point (with PC-number). Otherwise, as can be seen in Figure 6-7 (b), the question pages could provide more than two options to respond, which range from Good Point to some scales of PCs, based on the correlation of company current condition with the PC description.

(a) 

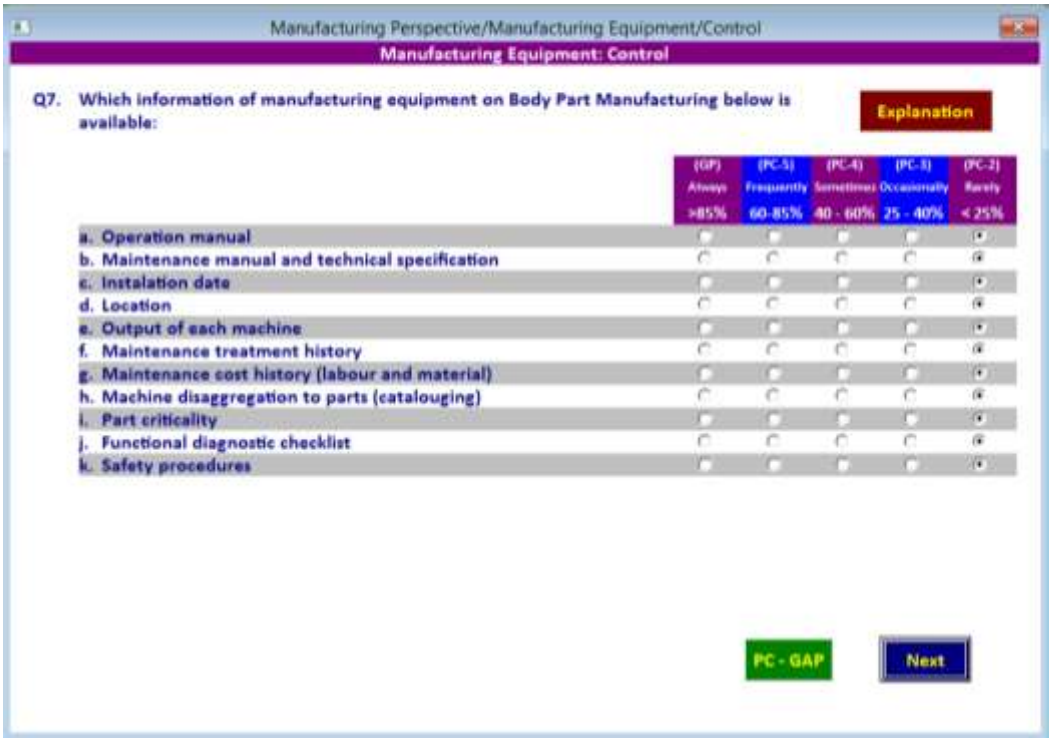
(b) 

Figure 6-7 The user response pages within the KBIMSO application

The statements presented on KBIMSO application, both the questions and the answers are managed carefully to ensure that the users can respond with correct answers. However, it is important to facilitate the KBIMSO with a supporting tool to avoid potential ambiguity and misinterpretation. There are some approaches could be used to tackle wrong response, such as using the Bayesian method, fuzzy logic or Explanatory Facility. The KBIMSO model is complemented with the latter one, the *Explanatory Facility,* to avoid ambiguity for the user to response the questions, an example is shown in Figure 6-8. This facility contains the reason of how such KB rule is risen to make a recommendation and the reason of why the certain PC level is appointed to that KB rule.

Figure 6-8 The Explanation page within the KBIMSO application

Overall, KBIMSO application can support Knowledge Management to improve business management (Turban et al., 2008). Knowledge storing and knowledge sharing can ensure that the knowledge regulates within the company. As the implication, the company will not lose such knowledge to make correct decisions even though some experts leave the company. The recommendation and decision made based on KBIMSO model can also be traced and reviewed again to see the effectiveness of rectification and improvement actions.

Meanwhile, the explanation of PC-number attached on each question is presented in the PC-GAP page, as shown in Figure 6-9. This PC-GAP page is intended to show the description of each PC as part of GAP analysis. The rank of PCs is sorted based on the importance of certain KB rule to the system performance, the severity level of its absence, and the impact of improvement.

This page is always attached on each response page to help the users during answering the questions to see the importance of certain KB rules and the impact of the absence of such KB rules based on GAP analysis.

Problem Categories (PCs) and description of GAP Analysis for KBIMSO

Problem Category	Description
PC-1	**This indicates a significant problem**, which involves pre-requisites to the system and may impact overall system performance in a short period of time. It should and can be resolved in a short term and through appropriate and logical improvement and implementation plan. The solution of the problem is likely to provide a real short term benefit.
PC-2	**This indicates a serious problem**, which involves pre-requisites to the system and may impact overall system performance after a period of time. It should and can be resolved in a short term and through appropriate and logical improvement and implementation plan. The solution of the problem is likely to provide a real short term benefit.
PC-3	**This indicates quite a major problem**, which is most likely to have pre-requisites to the system and may impact overall system performance after a period of time. It is better dealt with as part of an appropriate and logical improvement and implementation plan. The solution of the problem is likely to provide a real short term benefit.
PC-4	**This indicates a major problem**, which is likely to have pre-requisites to the sub-system and is better dealt with as part of an appropriate and logical improvement and implementation plan. The solution of the problem is likely to provide a real short term benefit.
PC-5	**This indicates a moderate problem**, which is likely to have pre-requisites to the sub-system. It can be dealt immediately without an appropriate and logical improvement and implementation plan. The solution of the problem is likely to provide a short-term benefits.
PC-6	**This indicates a minor problem**, which is likely to have pre-requisites to minor activities in the sub-system. It can be dealt immediately without an appropriate and logical improvement and implementation plan. The solution of the problem might provide a short-term benefits.
PC-7	**This is not a serious problem**. Although it could be dealt immediately, it is unlikely to produce short term benefit. Therefore, it should only be dealt with if it is a pre-requisite for other things.
PC-8	**This is not really a problem**. However it is important to consider certain situations as future improvement.
PC-9	**This is not really a good or bad point itself**. The questions associated with this category are primarily asked to identify certain situations in the environment, which upon subsequent probing by succeeding questions, may well reveal problems.

OK

Figure 6-9 The PC – GAP page within the KBIMSO application

The explanations of all modules and sub-modules in *Strategic Stage* of KBIMSO are detailed in the following sections.

6.3.1 Level 1.1 – Company Statement Analysis Module

Company Statement Analysis Module consists of two sub-modules, *Value Socialisation Sub-Module* and *Value Integration Sub-Module*. The flowchart of this module is presented in Figure 6-10. *Value Socialisation Sub-Module* is intended to check the availability of company statement, the involvement of management team to create it, the content of company statement and the socialisation of the values to the stakeholder. Furthermore, *Value Integration Sub-Module* emphasises on value empowerment, integration of stakeholders' concern, as well as the commitment of management team to support the values.

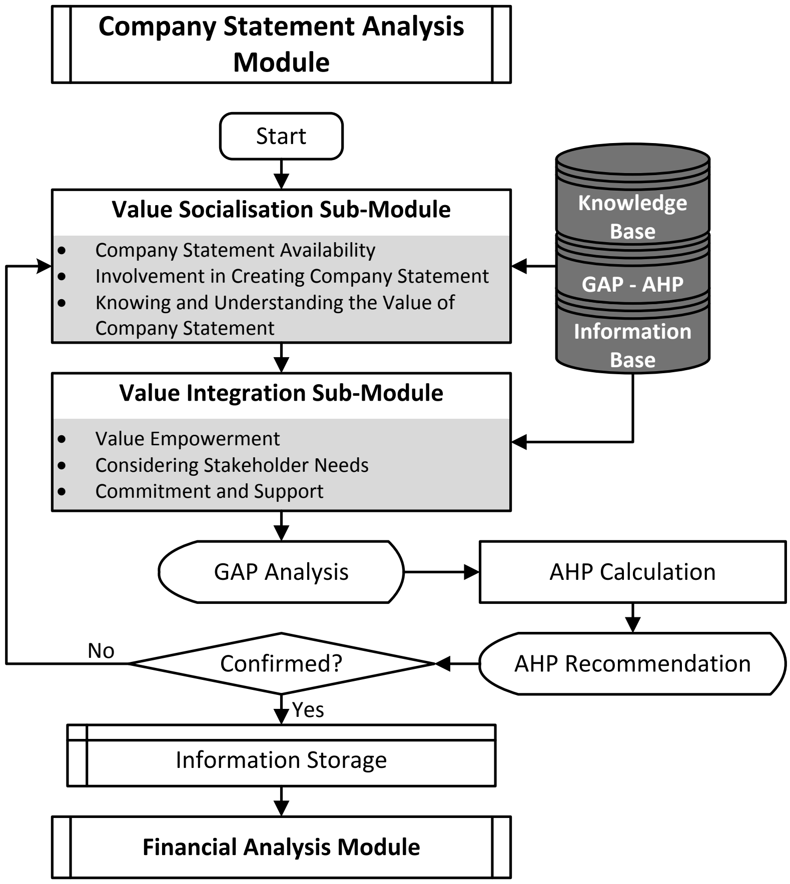


Figure 6-10 Flowchart of Level 1.1 – Company Statement Analysis Module

Referring to Figure 6-10, there are some aspects discussed in *Value Socialisation Sub-Module*. All components of the company statement, which are vision, mission, and objectives, need to be presented to foster the business. They inform the ideal state of what the company wants to be in the future. The company without company statement will cause business frustration and failure (Drucker, 2011) as there is no clear goal of what the company wants to achieve. Company statement is important to assist top-level managers in developing relevant objectives and strategies to achieve company's goal (DuBrin, 2010). Moreover, the involvement of all company member in building up the company statement leads to strong commitment and motivation to represent the company's values within the daily activities and encourage teamwork to achieve the goal (Mullane, 2002). Achieving company statement also requires the company members to know and understand the values (Bart, 2001). Sharing the values of company statement to all company members is the starting point to learn, adapt, and practice the values (Orhan et al., 2014). It can also announce the commitment of the company in order to meet its stakeholders' expectation.

Value Integration Sub-Module discusses the company efforts to integrate values of company statement into organisation culture. The developed strategies and operations on lower level management functions are rooted from and considered as the products of mission statement (Joachim, 2010). A typical mission identifies the key stakeholder needs and the company commitment to meet these needs (Mullane, 2002). The clear and specific statement about stakeholders' concern within company statement will provide a better balance among stakeholders' interests and will help to determine resources allocation (Bart, 1998).

The example of generated KB rules of the *Company Statement Analysis Module* for *Value Socialisation Sub-Module* is illustrated as the following (only some KB rules presented):

IF	*Top Level Management can explain the values of company statement (Yes: GP; No: BP-PC-2)*
AND	*Middle Level Management can explain the values of company statement (Yes: GP; No: BP-PC-3)*
AND	*Lower Level Management can explain the values of company statement (Yes: GP; No: BP-PC-4)*
AND	*The relevant key aspects of company statement are visually displayed on the administrative office (Yes: GP; No: BP-PC-3)*
AND	*The relevant key aspects of company statement are visually displayed on the shop floor (Yes: GP; No: BP-PC-3)*
AND	*The values of company statement are explained during induction session to new staff (Yes: GP; No: BP-PC-4)*
AND	*There is a periodic meeting for all company members to get updates about company statement values and future objectives (Yes: GP; No: BP-PC-4)*
THEN	*The company statement has been socialised properly to the entire organisation*
OR	*The company statement has not been socialised properly to the entire organisation*
OR	*The company statement has not been socialised to the entire organisation*

Each level of managers requires a different level of responsibility for understanding and adopting values of company statement. Top Level Management is required to understand the values of company statement and can explain it as the guidelines to direct the lower management levels. Lack of knowing and understanding the values of company statement by Top Level Management is very crucial and may cause disorientation of aim and action for overall company members thus categorised as PC-2. This risk is decreased on the lower managers thus the PC appointed to the absence of such KB rules is PC-3 for Middle Level Management and PC-4 for Lower Level Management.

Furthermore, the company needs to provide the written form of the company statement as the public statements of the company (Benligiray et al., 2013). The display of company statement within the company area is one way to announce the values as well as motivate and remind the company members about what the company is going to achieve (Orhan et al., 2014). Meanwhile, the presentation of company statement on public space will attract potential customers to find more about the company and its products. Considering the importance of the display of company statement within the company spaces as well as public spaces, the absence of this is categorised as PC-3.

Periodic meeting for all company members is important to provide updates on company objectives, strategy, and plan. It will support all members to work in the same direction to achieve the company goal. Lack of getting updates on company statement values and future objectives may cause disorientation of aim and action, thus categorised as PC-4.

6.3.2 Level 1.2 – Financial Analysis Module

Every business measures financial performance since it indicates how the company runs, survives and competes as well as indicating how the company gives financial value added to the shareholders (Kaplan and Norton, 1996b). *Financial Analysis Module* is also intended to analyse a company's overall performance and assess its current financial condition as the way to know its position against standard criteria and the possibility of potential improvement (Brealey et al., 2001). The flowchart of *Financial Analysis Module* is presented in Figure 6-11.

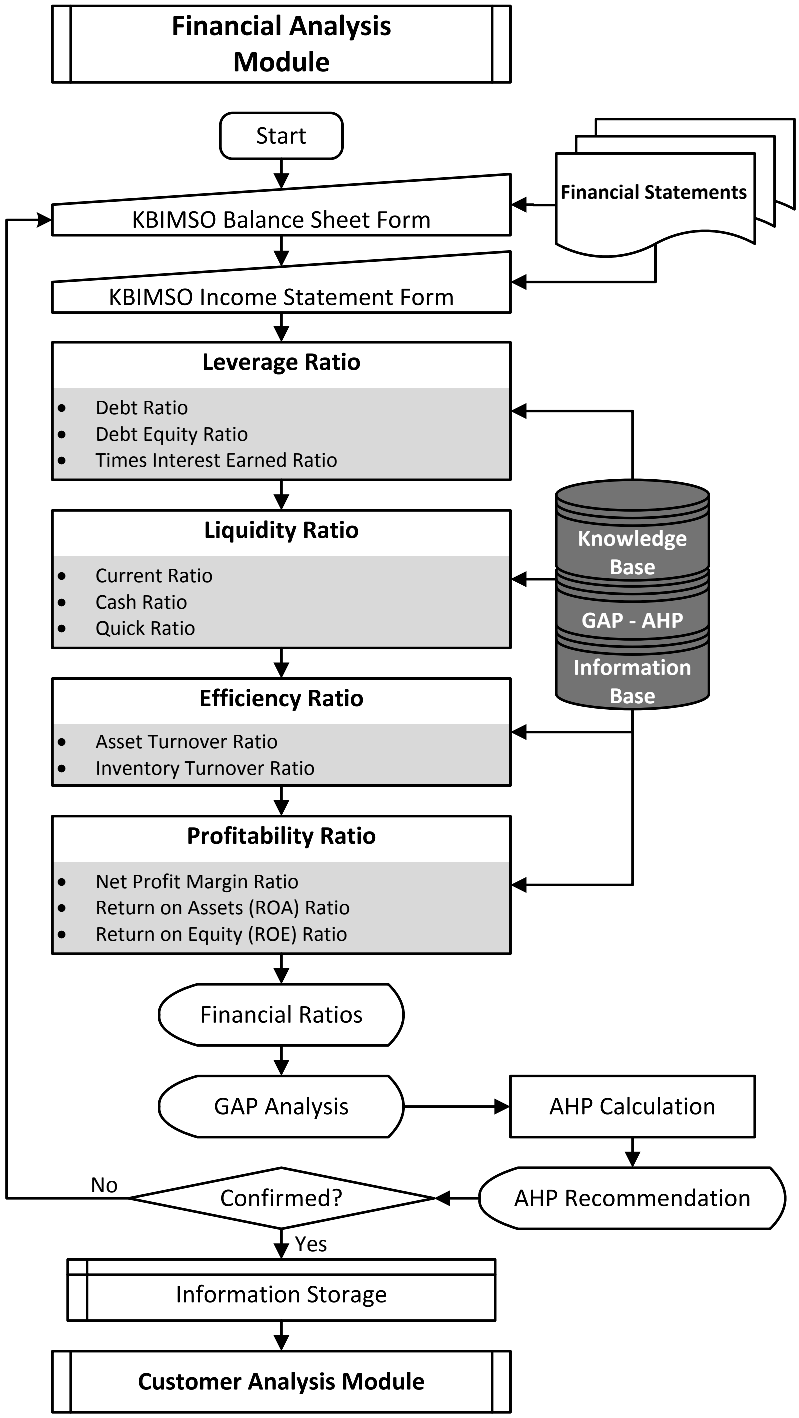


Figure 6-11 Flowchart of Level 1.2 – Financial Analysis Module

The input used to analyse financial performance in the KBIMSO model is the official financial statement released by the company. There are two documents required to response the KB rules in *Financial Analysis Module*, which are Balance Sheet and Income Statement. Balance Sheet indicates the financial condition of the company at a particular moment of time (Bertoneche and Knight, 2001). It presents a summary of the company's assets and the source of money used to buy those assets (Brealey et al., 2001). Meanwhile, Income Statement is a financial statement which shows the flow of transactions over a period of time (Bertoneche and Knight, 2001). It reports the company's income and expenses and calculates the difference between these two, either in term of profit or loss (Brealey et al., 2001). By considering that those financial statements (Balance Sheet and Income Statement) have been provided by the company on a particular format, the KB rules generated on *Financial Analysis Module* for KBIMSO also refer to the available variables. Therefore, all analyses for this module follow the standardized accounting references to measure the company financial performance.

The output of *Financial Analysis Module* is presented in financial ratios. There are four sub-modules considered to assess financial performance, which are *Leverage Ratio*, *Liquidity Ratio*, *Efficiency Ratio*, and *Profitability Ratio*. Each financial ratio has some indicators to reach the conclusion for that particular ratio, as can be referred again to Figure 6-11. The example of generated KB rules of the *Financial Analysis Module* for *Profitability Ratio Sub-Module* is illustrated as the following (only some KB rules presented):

IF *the Net Profit Margin Ratio (NPMR) in last year > two years ago (Yes: GP; No: BP-PC-2)*
AND *the NPMR in two years ago > three years ago (Yes: GP; No: BP-PC-3)*
AND *the value of NPMR in last year is positive (Yes: GP; No: BP-PC-2)*
AND *the value of NPMR in two years ago is positive (Yes: GP; No: BP-PC-3)*
AND *the value of NPMR in three years ago is positive (Yes: GP; No: BP-PC-3)*
AND *the Return on Assets (RoA) in last year > two years ago (Yes: GP; No: BP-PC-2)*
AND *the ROA in two years ago > three years ago (Yes: GP; No: BP-PC-3)*
AND *the value of RoA in last year is positive (Yes: GP; No: BP-PC-2)*
AND *the value of RoA in two years ago is positive (Yes: GP; No: BP-PC-3)*
AND *the value of RoA in three years ago is positive (Yes: GP; No: BP-PC-3)*
THEN *the Profitability Ratio has positive values and increased in three consecutive years*
OR *the Profitability Ratio has positive values and decreased in three consecutive years*
OR *the Profitability Ratio has negative values and increased in three consecutive years*
OR *the Profitability Ratio has negative values and decreased in three consecutive years*
OR *the Profitability Ratio has fluctuated in three consecutive years*

The above set of KB rules emphasises the calculation of *Profitability Ratio* to assess the company's ability to earn a profit and return its investment in the last three years. As one of the methods to show the financial health of the company, it gives a sign for potential improvement on every function within the company, includes maintenance function. *Profitability Ratio* is assessed through *Net Profit Margin Ratio (NPMR)*, *Return on Assets (ROA) Ratio*, *Return on Equity (RoE) Ratio*, and *Return on Investment (ROI) Ratio*. A positive value of *NPMR* in last year is considered to be very critical to show company financial health thus the negative value is categorised as PC-2. Similarly, the positive trend of *NPMR* between last year and two years ago is also critical thus the absence is categorised as PC-2. Meanwhile, the negative values of *NPMR* in two and three years ago and the negative trend of *NPMR* between two years ago and three years ago are categorised as PC-3. Furthermore, KB rules for other sub-modules are generated with a similar pattern.

6.3.3 Level 1.3 – Customer Analysis Module

Customer Analysis Module aims to review business strategy in term of customer perspective. The discussion focuses on *Customer Satisfaction* and *Market Share Sub-Modules*. Customer satisfaction is one of the important goals to be achieved by the company in order to keep its existence in the business. Customer satisfaction is reached when the product or service can meet or exceed customer expectation (Kaplan and Norton, 1996b). There are some aspects of which the company needs to manage in *Customer Satisfaction Sub-Module*, which are response time, quality, safety, price, and intangible aspect, as shown in the process flowchart of *Customer Analysis Module* in Figure 6-12. On the other hand, *Market Share Sub-Module* discusses the identification of market share in a variety of scope; national, regional, and global market share.

At the beginning of *Customer Satisfaction Sub-Module*, the KB rules are emphasised to reveal the commitment of management team in supporting customer satisfaction programmes. Different level of management has different roles contributed to ensure that the strategies and objectives can be planned, organised, measured, controlled and evaluated appropriately. The involvement of different functions, either directly or indirectly, to support customer satisfaction programmes is also investigated.

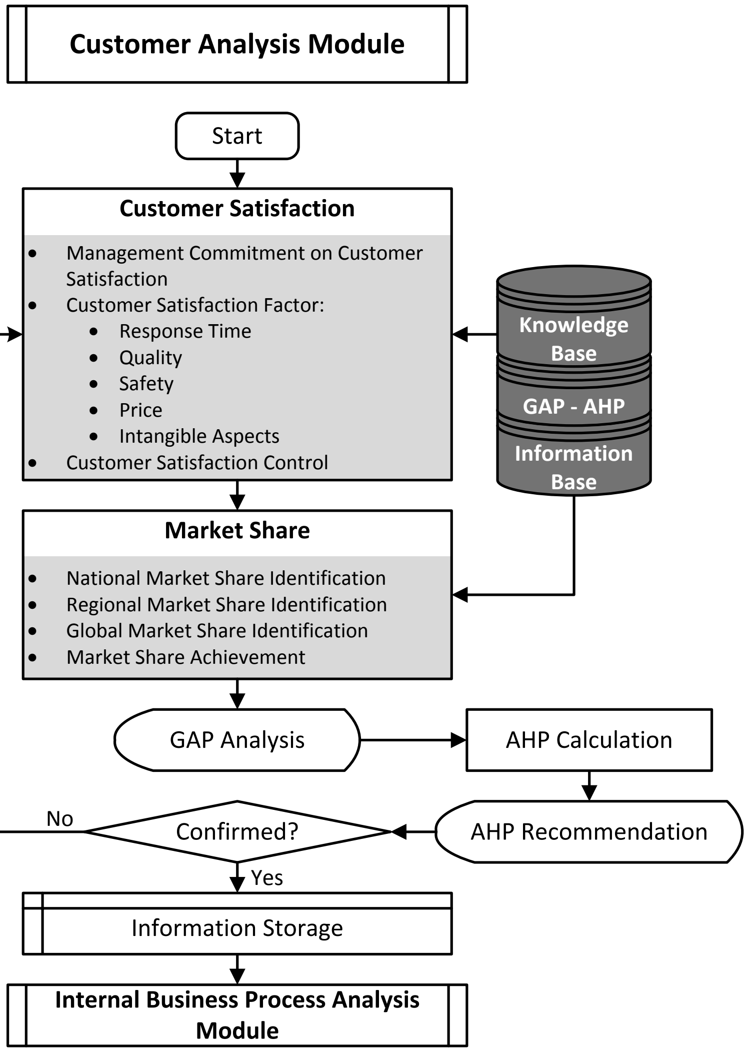


Figure 6-12 Flowchart of Level 1.3 – Customer Analysis Module

Furthermore, *Customer Satisfaction Sub-Module* discusses important factors to achieve customer satisfaction. Those are response time, quality of product, safety, price, and intangible aspects. Response time refers to the time duration of meeting the customer demand, from receiving the order until delivering it to the customer. It highly relates to the ability of the company to provide on-time delivery based on agreed due-date (Hill and Hill, 2009). Dimensions of quality of product that are expected to be provided by a company to satisfy its customers are performance, features, reliability, aesthetics, durability, conformance, serviceability, and perceived quality (Garvin, 1987). Safety is also another important factor should be measured in *Customer Satisfaction Sub-Module* since the automotive product is one of the products subject to liability for any physical harm caused to the user, or others according to the 'theory of strict liability' (Evans and Lindsay, 2010). The company has to consider price as one of the competitive aspects to gain customer satisfaction. The price comparison from the competitors could be taken from the quality of product, niche product, product lifecycle, and intangible aspect of the product (Mohamed and Khan, 2012). The latter aspect includes image, reputation, and relationship that attract customers to be loyal to the company and to define the values of product and service (Kaplan and Norton, 1996a).

The company needs to decide price against the competitor within a certain level of quality in order to achieve customer satisfaction. It means that the customers need to be informed of how their money spent and how to satisfy them through the quality of products/services. The appreciation of customer for the values they got can guide the company to compete related to price (Wibisono, 2003).

The most accurate way in measuring customer satisfaction is through a survey to the customers since the perceptions of performance are more important than the company's actual performance (Khan and Wibisono, 2008). Meanwhile, to confirm the result of the survey, the company could measure its achievement through Customer Retention, Customer Acquisition, Customer Profitability, and Market Share (Kaplan and Norton, 1996a). Customer Retention represents the loyalty of existing customer with the company's products and services (Kaplan and Norton, 1996a). It shows the number of existing customers who rebuy either same or different product from the company. Customer Acquisition indicates the increase in the number of customers (Kaplan and Norton, 1996a). It shows the increase in the number of customers who buy products from the company. Customer Profitability represents the profit obtained from the company expense special support for particular customer or segment (Kaplan and Norton, 1996a).

The company has to know which segment it wants to serve, what kind of product or service to sell, and what value proposition to emphasize (Drucker, 2011). Marketplace, a.k.a. addressable market indicates total revenue opportunity to a product or service (Bagley, 2013). Market share, a.k.a. available market is the portion of marketplace where the company is realistically competing (Bagley, 2013). It is the initial stage to analyse what the market wants and how products win in the marketplace. In this research, market share is classified into three coverages. First, national market share indicates market share within a country (i.e. Indonesia). Second, regional market share indicates market share within a particular group of countries (i.e. Southeast Countries). Third, global market share indicates market share over the world. Meanwhile, identifying the competitors is also useful to know how big the competition is and the proportion of market share relatives to the number of competitors.

The example of generated KB rules of the *Customer Analysis Module* for *Customer Satisfaction Sub-Module* is illustrated as the following (only some KB rules presented):

IF	*The company considers quality of product as an important factor to achieve Customer Satisfaction (Yes: GP; No: BP-PC-1)*
AND	*In Customer Satisfaction programme related to quality of product, the company takes product performance into account (Yes: GP; No: BP-PC-1)*
AND	*In Customer Satisfaction programme related to quality of product, the company takes product features into account (Yes: GP; No: BP-PC-1)*
AND	*In Customer Satisfaction programme related to quality of product, the company takes product reliability into account (Yes: GP; No: BP-PC-1)*
AND	*In Customer Satisfaction programme related to quality of product, the company takes product conformance into account (Yes: GP; No: BP-PC-1)*
AND	*In Customer Satisfaction programme related to quality of product, the company takes perceives quality of product into account (Yes: GP; No: BP-PC-1)*
THEN	*The company has recognised critical factors to reach Customer Satisfaction in term of quality of product*
OR	*The company has recognised some critical factors only to reach Customer Satisfaction in term of quality of product*
OR	*The company has not recognised all critical factors to reach Customer Satisfaction in term of quality of product*

Product performance refers to a product's primary operating characteristics (Garvin, 1987). The quality of product is the most important variable that should be managed tightly. It is therefore crucial that customer satisfaction programmes concern on aspects of product quality. Considering the impact of quality of product to achieve customer satisfaction, the absence of managing each quality dimension of product is categorised as PC-1.

6.3.4 Level 1.4 – Internal Business Process Analysis Module

Internal Business Process Analysis Module is intended to review business strategy in term of internal business process, with the process flowchart shown in Figure 6-13. It is required to enable the company to deliver the value proposition to the customer as well as to satisfy the shareholders with excellent financial return (Kaplan and Norton, 1996b). The discussion includes *Product*

Development and *After-Sale Service Sub-Modules*. The discussion on *Product Development Sub-Module* encompasses market research as the initial process. It is then continued with product innovation, particularly on reducing cycle time, increasing quality, and reducing cost. Furthermore, *After-Sale Service Sub-Module* discusses the provided service to support the customer needs after purchasing product.

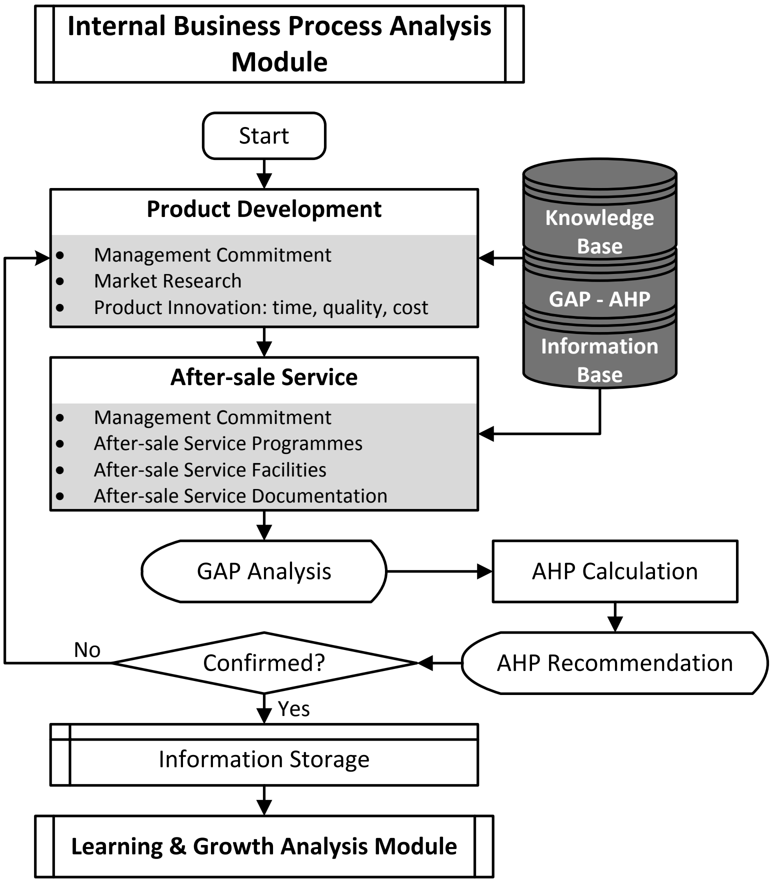


Figure 6-13 Flowchart of Level 1.4 – Internal Business Process Analysis Module

Every single task in Internal Business Process is intended to meet shareholders and targeted customer expectation (Kaplan and Norton, 1996a). The KB rules in *Product Development Sub-Module* are started by confirming management commitment in supporting product development programmes. The KB rules investigate all management levels regarding their roles in product development programmes, the coordination and integration of different functions within the organisation to support product development programmes, and evaluation.

The next step in *Product Development Sub-Module* is investigating product development process regarding market research. The first step in market research is intended to understand the marketplace where the company markets its product (Kotler and Armstrong, 2012). It helps the company in understanding market size, identifying the market segment and their preferences, identifying competitors, assimilating the product, and deciding the suitable price for such product/service (Kaplan and Norton, 1996a). It could help the company to know customer behaviour, regional culture, ethics, and law to ensure the company providing a legal and acceptable product or service (Bagley, 2013). In turn, it also promotes an obvious interaction with the community (Mullane, 2002).

Another aspect discussed in *Product Development Sub-Module* is product innovation. Innovation on *Product Development Sub-Module* is intended to increase the value of products to the customers by enhancing quality, speeding time to market, and reducing cost (Koufteros et al., 2005; Ragatz et al., 1997). These aspects are critical in product development because life cycles are getting shorter, and obsolescence is getting faster than in the past while the competition is getting tight (Griffin, 1997). Therefore, the company has to bring the product faster to the market.

To achieve those above targets, effective collaboration with suppliers is important to reduce cost, improve quality of material, reduce product development time, and improve access to applications of technology (Ragatz et al., 1997). Customer as the end-users has an important role to decide what product they need to meet their requirement. Thus integrating customer needs into product development process will help the company to develop a qualified product (Torres et al., 2013). Meanwhile, maintenance plays a role as the facilitator to support manufacturing process working on its expected performance. It also contributes substantially to minimize equipment downtime, increasing productivity, improving quality and assuring equipment reliability (Duffuaa et al., 1999). Quality is also directed as the built-in process of manufacturing in both technical and cultural ways to lead to continuous improvement of product design and process quality (Morgan and Liker, 2006). The latest one, implementation of the Knowledge-Based System can be used to record all processes, reuse the data and to avoid repetitive tasks which then promote the best practice to reduce cycle time. Creating a supporting system (i.e. Knowledge-Based System) to facilitate the experts from different functions to share their knowledge is important to fasten the development process, increase uniformity and consistency, and avoid trial-error (case-based reasoning) (Prasad, 2014).

Another sub-module in *Internal Business Process Analysis Module* is *After-Sale Service Sub-Module*. It is one of the important factors that should be managed to improve company competitiveness in the business competition since the customers now becoming more criticize not only to the product offered but also to the service offered after they buy the product (Wibisono, 2003). The aspects covered in *After-Sale Service Sub-Module* include policies and procedures, centres, and documentation. After-sale service policies and procedures include warranty, repair, and recall policies and procedures, which ensure that the customer always gets the best quality of product. After-sale service centres support after-sale service programmes by providing required information and answering all queries related to company, products and related services. It shares information of company profile, dealers, spare parts, services, complaints, etc. The last but not least, after-sale service documentation is required to record all information from both company and customers related to product and given treatments to such product.

The example of generated KB rules of the *Internal Business Process Module* for *Product Development Sub-Module* is illustrated as the following (only some KB rules presented):

IF	*The company considers the importance of market research as an initial process of product development process (Yes: GP; No: BP-PC-9)*
AND	*In market research, the company learns about customer requirements regarding market size (Yes: GP; No: BP-PC-2)*
AND	*In market research, the company learns about customer requirements regarding customer behaviour (Yes: GP; No: BP-PC-2)*
AND	*In market research, the company learns about customer requirements regarding geographic condition (Yes: GP; No: BP-PC-2)*
AND	*In market research, the company learns about customer requirements regarding seasonality (Yes: GP; No: BP-PC-2)*
AND	*In market research, the company learns about customer requirements regarding culture (Yes: GP; No: BP-PC-2)*
THEN	*The company has done market research as the initial process of product development process*
OR	*The company has not done market research as the initial process of product development process*

The question of whether the company realises the importance of market research actually has no impact on the organisation since it is only asked to confirm the company existing position. However, the answer will guide to identify any problems in the organisation. Therefore, this initial question is categorised as PC-9 on GAP analysis. The next questions discuss the detail of market research. The absence of any aspects is categorised as PC-2 since it is crucial in conducting market research to figure out the comprehensive condition of the marketplace to support product development process.

6.3.5 Level 1.5 – Learning and Growth Analysis Module

Learning and Growth Analysis Module provides the support to strengthen the objectives from the other three perspectives (financial, customer, and internal business process) to be achieved (Kaplan and Norton, 2006). The key factors discussed in the KBIMSO on *Learning and Growth Analysis Module* are employee engagement, social issue, and environmental issue, as shown in the process flowchart of *Learning and Growth Analysis Module* in Figure 6-14.

Employees are the most important resource within the company to achieve business performance. Therefore, the company has to support them to fulfil their professional, personal, and social needs, in term of finding their livelihood and recognition to their social status and individual achievement and satisfaction (Drucker, 2011). Employee engagement encompasses different factors to encourage the engagement of the employees with their company. Not only fulfilling their professional job requirement, the company need to take into account their personal needs so the employees put passion, commitment and discretion on their job. Last but not least, the leadership and corporate culture play the important role to fulfil social needs in creating a convenient atmosphere for the employees to work comfortably beyond their expected performance.

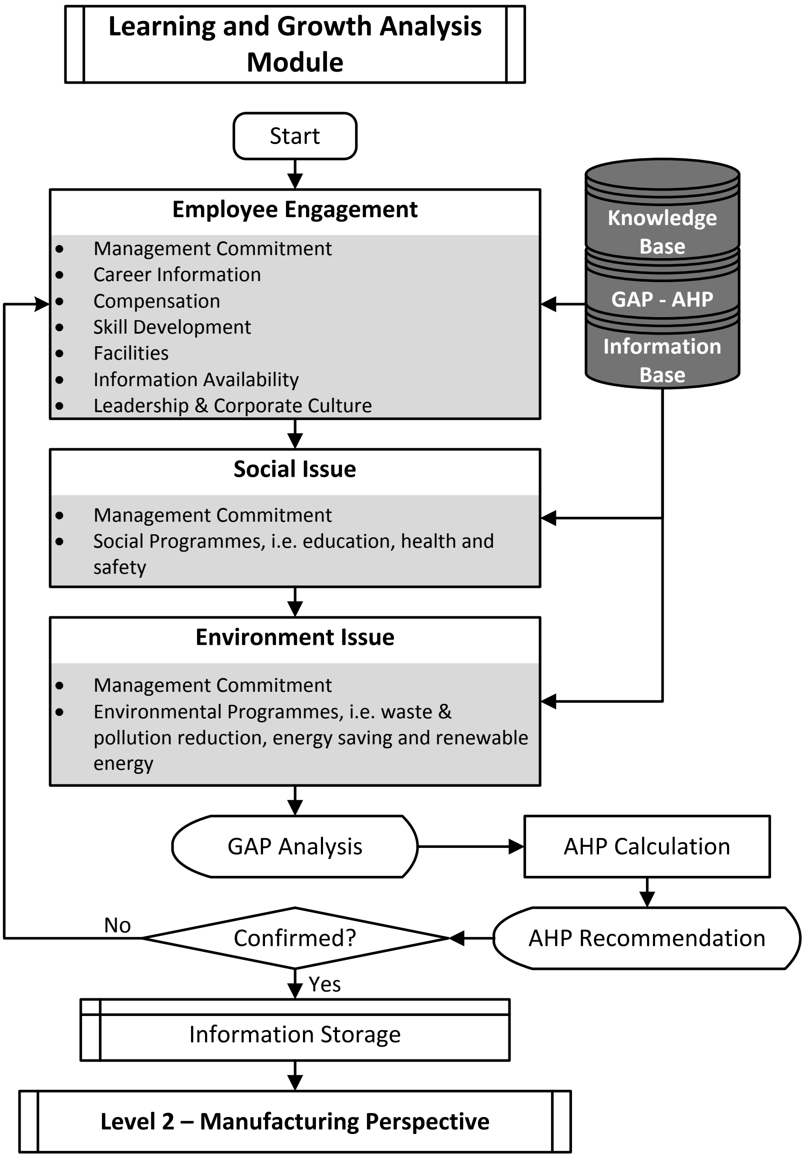


Figure 6-14 Flowchart of Level 1.5 – Learning and Growth Analysis Module

National and local laws should influence every aspect of Human Resource Management when taking decisions of employment, such as compensation – including pay and benefits – which is considered as a major role in Human Resource Management (DuBrin, 2010). Competitive compensation will help the company to get more qualified employees and retain them within the company (Williams, 2009). Also, skill improvement provides opportunities for employees to develop the job-specific skills, experience, and knowledge they need to complete their jobs or to improve their performance. Facilitating the employees with skill improvement is very important to support the employees to adapt to dynamic changing and new technology. Communication and cooperation to enable knowledge sharing across the organisation are also important factors to increase flexibility, efficiency and retain knowledge within the organisation (Evans and Lindsay, 2010). Leadership is another important point to evaluate as it influences the corporate culture and motivation to achieve organisation goal. The upper management levels need to show their commitment to the lower management levels that they fully support all programmes released (Burrill and Ledolter, 1999). After all, to confirm the performance of employee engagement programmes, some measurement could be used such as Employee Satisfaction Survey, Employee Retention, and Employee Productivity.

Success for a company is not only defined as being good for business but also be good for the community, by managing social impact and social responsibility (Drucker, 2011). It is a work-collaboration among the company, government, and individual citizens (Crowther and Aras, 2008). It encompasses social welfare initiatives and sustainable environmental programmes in order to provide a sustainable community. Social programmes are related to company contribution on enhancing social value such as poverty, human right, consumption reduction, and public health, while environment programmes are related to company concern on environmental matters, such as energy saving, renewable energy, climate change, global warming, and pollutions (Ledoux et al., 2005). Social and environment involvement may not provide immediate benefit to the company but instead promoting positive social responsibility to the community.

The example of generated KB rules of the *Learning and Growth Module* for *Employee Engagement Sub-Module* is illustrated as the following (only some KB rules presented):

IF *The company considers that fulfilling employee needs is an important aspect of Employee Engagement (Yes: GP; No: BP-PC-9)*
AND *The company keeps monitoring any changes in the employee laws or industrial regulations (Yes: GP; No: BP-PC-2)*
AND *The company provides the employees with clear and structured information about right and obligation (Yes: GP; No: BP-PC-2)*
AND *The company provides the employees with clear and structured information about job description and procedures (Yes: GP; No: BP-PC-2)*
AND *The company provides the employees with clear and structured information about career plan (Yes: GP; No: BP-PC-3)*
AND *The company provides the employees with clear and structured information about rotation scheme (Yes: GP; No: BP-PC-4)*
AND *The company provides the employees with clear and structured information about reward scheme (Yes: GP; No: BP-PC-6)*
THEN *The company has provided transparent career information for its employees*

OR *The company has not fully provided transparent career information for its employees*

The KB rules above are generated as the source of facts to reveal whether the company has provided transparent career information for its employees. The first KB rule is dedicated to check whether the company has any concern about the importance of employee engagement. Since the question is intended to understand the company circumstance, there is no real impact to that question, thus the absence is classified as PC-9. On the next KB rules, the importance of each question varies based on the impact of the absence of such question to the system performance. The responsibility of the company to follow the current regulation and laws, to provide clear and structured information about right and obligation, and to provide clear and structured information about job description and procedures, are crucial to maintaining employee engagement thus categorised as PC-2. Furthermore, different level of PC is attached to the different KB rules regarding their importance toward employee engagement and overall system performance.

6.4 Level 2 – Manufacturing Perspective

Another factor examined at the *Strategic Level* is *Manufacturing Perspective*. The discussion in this section corresponds to some factors on manufacturing function which have high interaction with maintenance function. *Level 2 – Manufacturing Perspective* consists of *Manufacturing Equipment*, *Manufacturing Process*, and *Process Quality Modules*, particularly on Body Part Manufacturing. The detailed structure of *Level 2* is shown in Figure 6-15.

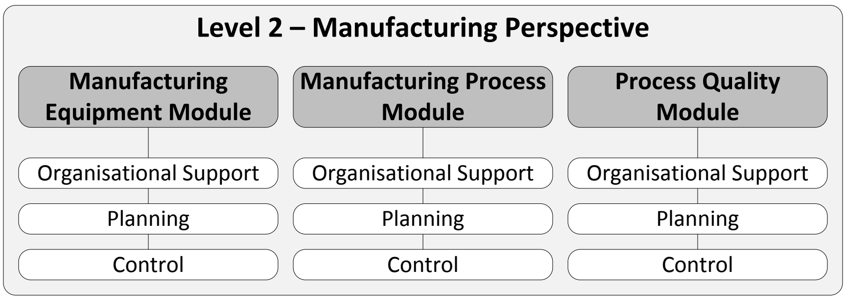


Figure 6-15 Detailed structure of Level 2 – Manufacturing Perspective

Although the KBIMSO can generally be implemented at different functions of the company or the entire system of organisation, the specific discussion of manufacturing and maintenance perspectives on Body Part Manufacturing is intended to control the validation process. The user can clearly refer to the current condition on that particular area, thus the response can be accurate. Furthermore, the implementation of KBIMSO can be adopted by other functions with some minor modifications. The process flowchart developed for *Level 2 – Manufacturing Perspective* is presented in Figure 6-16. The information gained from these aspects will then be sent to maintenance function to assist in describing the expected maintenance performance required to support manufacturing function.

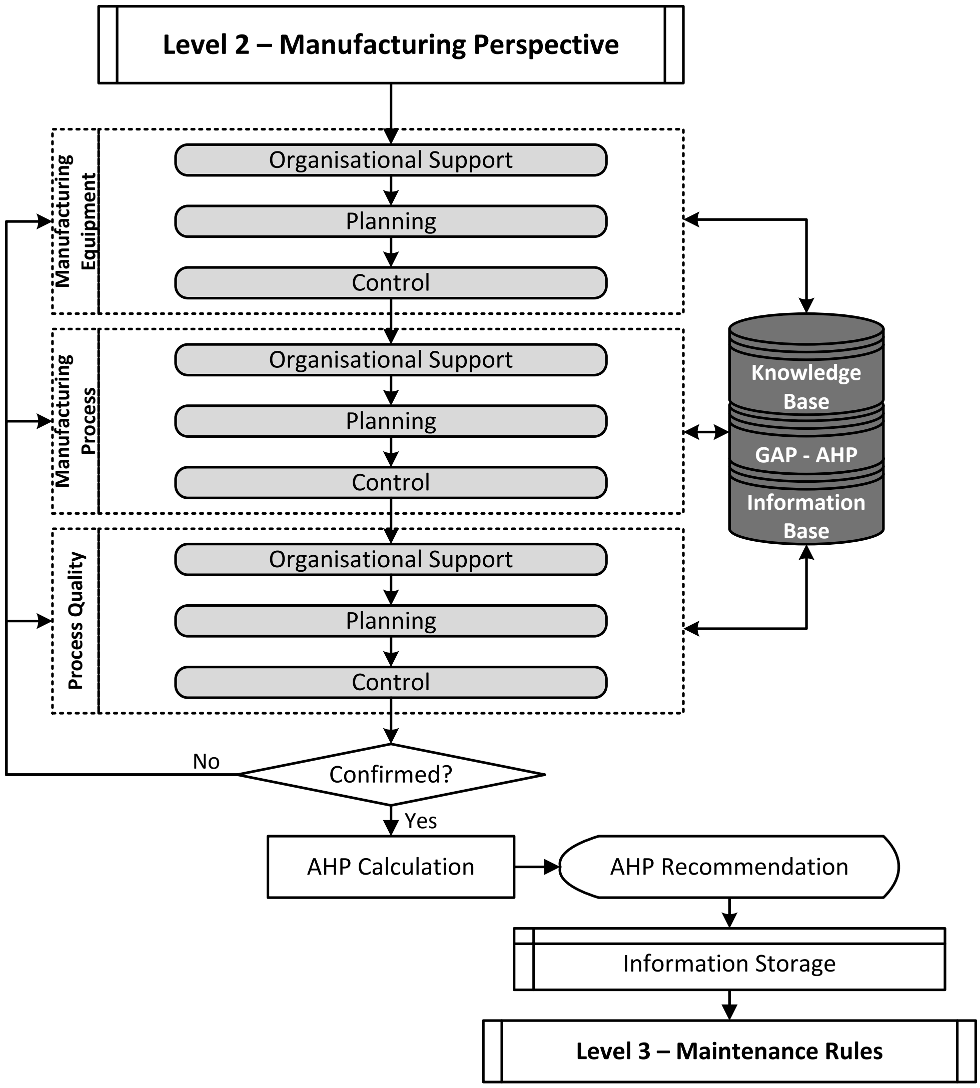


Figure 6-16 Flowchart of Level 2 – Manufacturing Perspective

Each module in *Level 2 – Manufacturing Perspective* has similarly three sub-module categorisations, which are *Organisation Support*, *Planning,* and *Control Sub-Modules*. *Organisation Support Sub-Module* emphasises the roles of different management levels to support the manufacturing performance within a particular aspect regarding policy, procedures, benchmarking, and resources. This sub-module also highlights the contribution of different functions to support decision making. *Planning Sub-Modules* encompasses the core performances required to achieve the benchmarks. Meanwhile, *Control Sub-Module* focuses on evaluating the current condition and achievements of certain programmes.

Similar with *Level 1* and the rest of the levels in KBIMSO model, the development of the KBIMSO framework into the KBIMSO application is initiated through generating and structuring the KB rules (as part of knowledge acquisition process) for each module and sub-module of the KBIMSO. The list of KB rules is structured in the form of questions about the existing implementation of the manufacturing process. The GAP analysis is embedded into each rule to investigate the gap between the current system and pre-requisite condition. Then a pair-wise comparison is conducted as part of AHP analysis. A detailed explanation of this process can be referred to Section 5.9. The development process of KBIMSO modules in *Level 2* is discussed in the following sections.

6.4.1 Level 2.1 – Manufacturing Equipment Module

Manufacturing Equipment (ME) Module is taken as the first module on *Manufacturing Perspective Level* since manufacturing equipment is the key aspect of the maintenance function to exist. The increase of automation of equipment also increase the role of maintenance to provide required service thus such equipment can work on its expected performance. This module consists of three sub-modules, which are *ME Organisation Support*, *ME Planning,* and *ME Control Sub-Modules*, with the process flowchart shown in Figure 6-17.

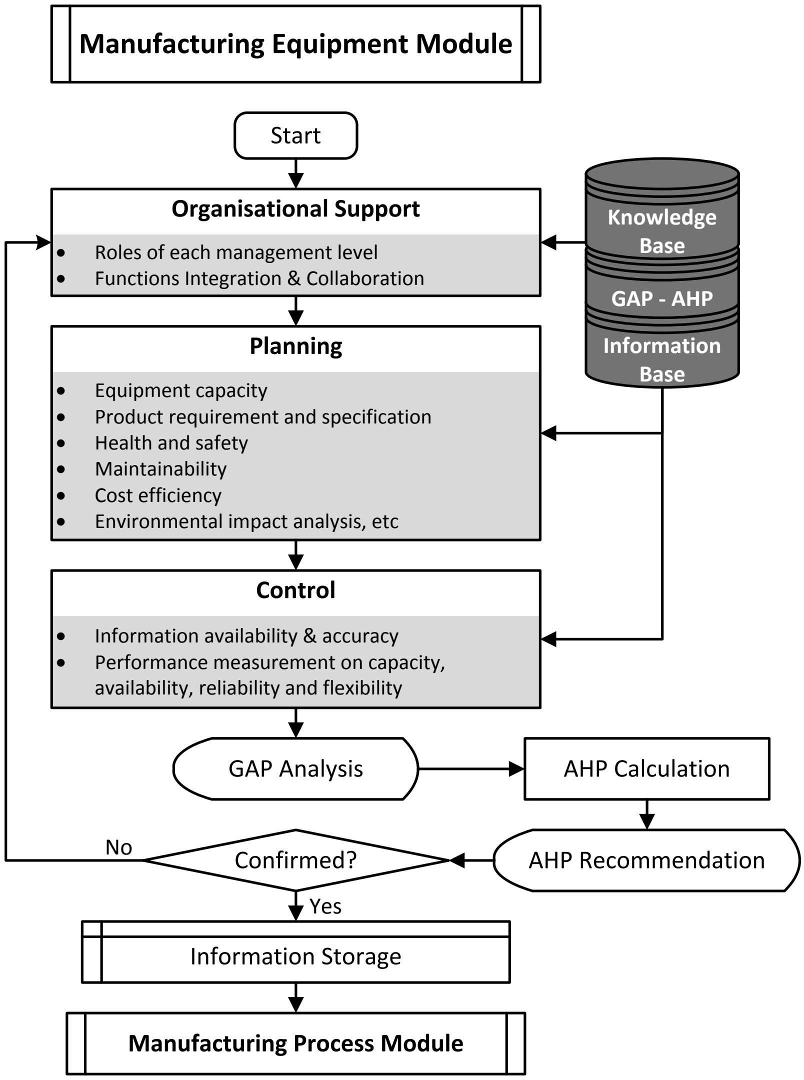


Figure 6-17 Flowchart of Level 2.1 – Manufacturing Equipment Module

Policy on manufacturing equipment is very important to provide the fundamental guidelines for the manufacturing equipment economically, socially, and environmentally. The commitment of all management levels to support the policies and the descended programmes related to manufacturing equipment can ensure that such programmes are executed with adequate resources and supervision.

The roles of Top Level Management are started by creating policies, assigning resources and budget, until reviewing the implementation towards particular target and benchmark. Furthermore, Middle Level Management as the intermediate level plays the roles to connect Top Level Management with Lower Level Management by socialising all policies and programmes and assisting the implementation of policy and programmes. Lower Level Management is then appointed to execute all programmes, from developing procedures, supervising the activities until reporting and reviewing the results.

To ensure that the decisions are taken from correct sources of information, the integration of relevant functions within the organisation is also required. As the supporting function for manufacturing department, maintenance department mainly requires the input from manufacturing department regarding the need for ensuring the manufacturing equipment performance. Meanwhile, other functions, such as quality, research and development, marketing, or supplier, contribute indirectly at different levels to guide the maintenance decision making, both on strategic and operational level.

In *ME Planning Sub-Module*, the KB rules are emphasised on how maintenance decision towards manufacturing equipment is influenced by some specific aspects of equipment and its use in the manufacturing plant. Those aspects include equipment capacity, product requirement and specification, health and safety, maintainability, cost efficiency, plant capacity and layout, environmental impact analysis, sustainable/renewable energy, technology change analysis, even related to company's orientation as world-class manufacturing.

Meanwhile, *ME Control Sub-Module* highlights the awareness of the company to maintain important information of manufacturing equipment and ensure that such information is always available and updated to assist maintenance decision making. It also investigates how such information can be accessed by appropriate staff. Another aspect discusses in *ME Control Sub-Module* is an evaluation of whether maintenance decisions are taken by considering specific circumstance of manufacturing equipment.

The example of generated KB rules of the *Manufacturing Equipment Module* for *ME Planning Sub-Module* is illustrated as the following (only some KB rules presented):

IF	*The decision of chosen manufacturing equipment of Body Part Manufacturing is taken based on equipment capacity (Yes: GP; No: BP-PC-1)*
AND	*The decision of chosen manufacturing equipment of Body Part Manufacturing is taken based on maintainability (Yes: GP; No: BP-PC-2)*
AND	*The decision of chosen manufacturing equipment of Body Part Manufacturing is taken based on cost efficiency (Yes: GP; No: BP-PC-3)*

AND	*The decision of chosen manufacturing equipment of Body Part Manufacturing is taken based on environmental impact analysis (Yes: GP; No: BP-PC-3)*
AND	*The decision of chosen manufacturing equipment of Body Part Manufacturing is taken based on sustainable/renewable energy (Yes: GP; No: BP-PC-4)*
AND	*The decision of chosen manufacturing equipment of Body Part Manufacturing is taken based on technology change analysis (Yes: GP; No: BP-PC-5)*
AND	*The decision of chosen manufacturing equipment of Body Part Manufacturing is taken based on towards world-class manufacturing (Yes: GP; No: BP-PC-6)*
THEN	*The key aspects have been taken into account for manufacturing equipment decision*
OR	*Not all key aspects have been taken into account for manufacturing equipment decision*

The procurement of chosen manufacturing equipment should be relevant to the company policy and orientation. The importance of each aspect varies from the most important one to the less important one. Thus the PC attached to each KB rule is also ranging from PC-1 to PC-6. For example, equipment capacity is the most important aspect to consider when choosing manufacturing equipment since it will influence equipment performance, equipment age, maintenance strategy, etc. Lack of considering equipment capacity might cause either overload or less productivity. Overload is leading to increase maintenance cost and decrease equipment economic age, while less productivity is leading to increase investment cost and decrease *Return on Investment (RoI)* ratio. Therefore, the absence of considering equipment capacity when choosing manufacturing equipment is categorised as PC-1. On the other hand, choosing manufacturing equipment based on company orientation as world-class manufacturing will have less impact on system performance, thus categorised as PC-6.

6.4.2 Level 2.2 – Manufacturing Process Module

In *Internal Business Process Analysis Module*, the KB rules of *Process Improvement* are shifted to *Manufacturing Process (MP) Module* to emphasize the role of manufacturing influencing maintenance function. It will be beneficial to split this out thus the significant factors of manufacturing related to maintenance are highlighted properly. This *Manufacturing Process Module* consists of three sub-modules which figure out the related aspects to support the performance of manufacturing process. The process flow chart of this module can be seen in Figure 6-18.

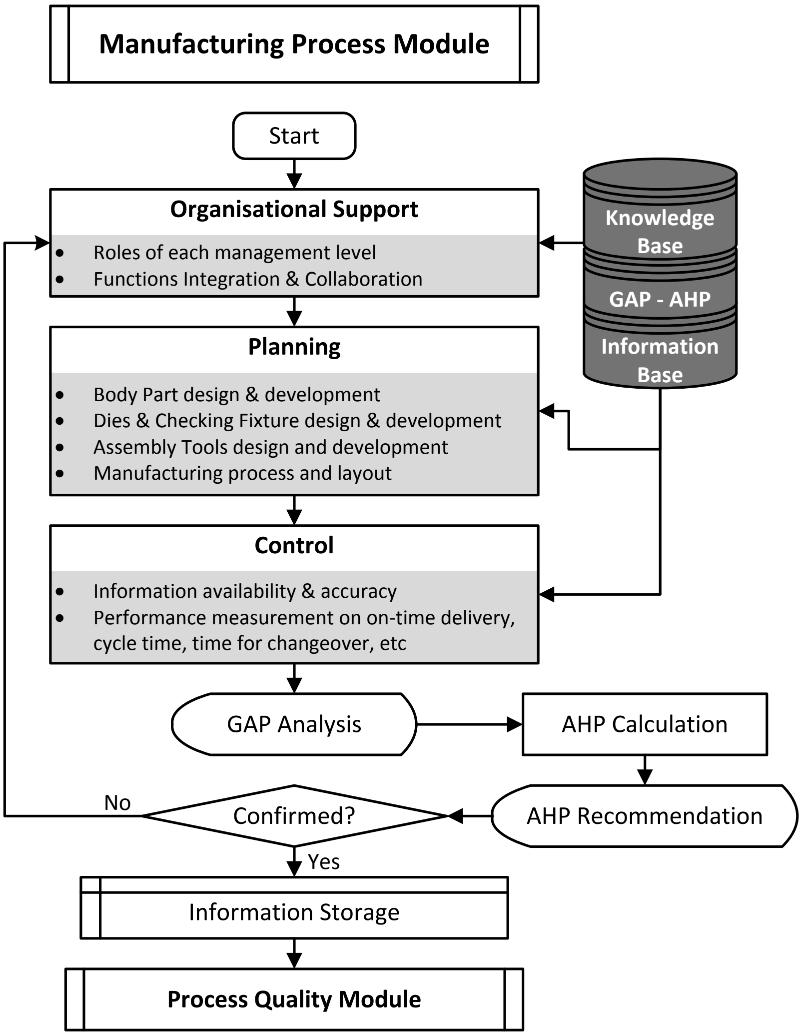


Figure 6-18 Flowchart of Level 2.2 – Manufacturing Process Module

Consistently on this KBIMSO model, the *MP Organisational Support Sub-Module* is intended to investigate the commitment of all management levels to provide required instruments to support manufacturing process, from policies, programmes, procedures, resources, until evaluation. Also, this sub-module contains KB rules to identify the contribution of different functions to support manufacturing process based on their speciality.

Product development in automotive company integrates conceptual design with market opportunity. The collaboration within a Research and Development team might involve internal and external stakeholder to develop product concept. The product concept itself should consider the fundamental quality specification of automotive product in term of physical performance, safety, and intangible aspects. The clay modellers or computer simulation engineers then transform the product sketches into detailed interior and exterior of the vehicle (Mohamed, 2012). On this line, the body part design team are involved in a variety of activities from idea generation to the manufacturing process (Udin, 2004).

MP Planning Sub-Module begins with Body Part Design and Development. The activities from Body Part Design to Body Part Manufacturing are confirmed through KB rules to assure that there is no step missed out. The initial important aspects to consider are the design of dies and fixture. These supporting tools are required to ensure the accuracy of critical points of body parts within the tolerance limit. By this, the KB rules check the availability of each process detail which is crucial to producing high quality of body part. KB rules are then generated on the manufacturing process which influences the process efficiency and waste reduction. These aspects are important to be considered in both tactical and strategic perspectives (Brown, 1996). They also influence the way of communication among workstations and overall layout of the shop floor.

The availability of required information on above phases is then checked through *MP Control Sub-Module*. Not only the availability of each item, but also the accessibility and accuracy of such information for the relevant staff. Then, the performance of manufacturing process is measured through some indicators by responding to a range of five categories.

The example of generated KB rules of the *Manufacturing Process Module* for *MP Organisational Support Sub-Module* is illustrated as the following (only some KB rules presented):

IF	*Manufacturing function is involved in Body Parts Manufacturing Process decision (Yes: GP; No: BP-PC-1)*
AND	*Maintenance function is involved in Body Parts Manufacturing Process decision (Yes: GP; No: BP-PC-1)*
AND	*Quality function is involved in Body Parts Manufacturing Process decision (Yes: GP; No: BP-PC-1)*
AND	*Marketing function is involved in Body Parts Manufacturing Process decision (Yes: GP; No: BP-PC-5)*
AND	*Supplier is involved in Body Parts Manufacturing Process decision (Yes: GP; No: BP-PC-6)*
AND	*Customer is involved in Body Parts Manufacturing Process decision (Yes: GP; No: BP-PC-7)*
THEN	*Decision of Body Part Manufacturing Process has involved a relevant cross-functional team*
OR	*Decision of Body Part Manufacturing Process has not involved a relevant cross-functional team*

The set of KB rules above emphasises the involvement of different functions and external stakeholders in the organisation. Besides manufacturing itself, the role of maintenance and quality functions is inevitable since these functions are supporting each other to reach the high quality of the product. Meanwhile, the importance of other functions and stakeholders is decreased and vary on a range of PC-5 to PC-7. The involvement of supplier and customer, for example, could help the design and development team to translate the market demand even though their existence is not so crucial to the entire development process.

6.4.3 Level 2.3 – Process Quality Module

The term of quality can be classified as product quality and process quality. Product quality includes all features which appear in the final product, in term of basic specifications and additional features to improve product value for the customer (Garvin, 1987; Evans and Lindsay, 2010). Different from the quality of product which focuses on the performance of finished goods to meet customer satisfaction, as discussed in Section 6.3.3, the KB rules on *Process Quality (PQ) Module* focus on how the company assuring the quality of manufacturing process. Process quality refers to the ability to produce at low cost, with assured delivery and flexibility (Brown, 1996). The combination of product and process quality will lead to a competitive product which is beneficial to both company and customer. The process flowchart of *Process Quality Module* is shown in Figure 6-19.

This module consists of three sub-modules, which are *PQ Organisational Support*, *PQ Planning*, and *PQ Control*. KB rules on *PQ Organisational Support Sub-Module* still highlight the management commitment to ensure that all activities related to ensuring process quality, particularly on Body Part Manufacturing, are facilitated and maintained properly. This sub-module also find out the role of different functions within the company to support this aspect of manufacturing either directly or indirectly based on their speciality.

After discussing the management support, KB rules on *PQ Planning Sub-Module* are directed to confirm whether the company has implemented Total Quality Management (TQM). TQM is considered as an integrated approach which involves culture and structure of the organisation to develop a total commitment to quality (Jonas et al., 2003). It requires the involvement of entire organisation's stakeholders to ensure long-term profitability and competitiveness. TQM coordinates with Total Productive Maintenance (TPM) as an approach to avoid poor practices in the manufacturing process as the way to provide the customers with quality competitive products (Seth and Tripathi, 2005). To assure process quality leading to zero defect and no waste, the KB rules are emphasised to know the implemented methods and tools to support process quality.

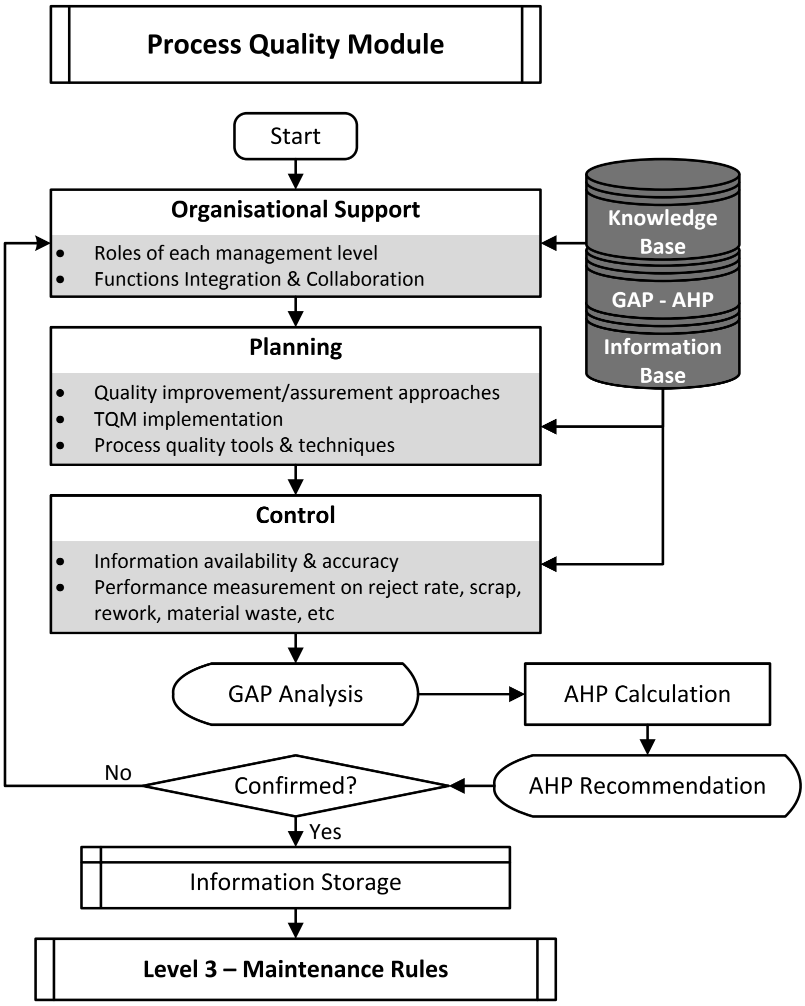


Figure 6-19 Flowchart of Level 2.3 – Process Quality Module

The last discussion in this module is *PQ Control Sub-Module*. The first part is to check the availability and accuracy of information related to the process quality. Next, the performance of process quality is measured through some quality variables, such as conformance to specification rate, reject rate, scrap, yield, supplier's quality incoming, etc.

The example of generated KB rules of the *Process Quality Module* for *PQ Organisational Support Sub-Module* is illustrated as the following (only some KB rules presented):

IF	*The company apply Total Quality Management (TQM) approach (Yes: GP; No: BP-PC-2)*
AND	*Employees are involved in TQM implementation (Yes: GP; No: BP-PC-2)*
AND	*Suppliers are involved in TQM implementation (Yes: GP; No: BP-PC-3)*
AND	*Distributors are involved in TQM implementation (Yes: GP; No: BP-PC-4)*
AND	*Customers are involved in TQM implementation (Yes: GP; No: BP-PC-6)*
AND	*Incoming Material Quality is the aspect emphasised in developing a relationship with suppliers for Body Parts manufacturing process quality (Yes: GP; No: BP-PC-2)*
AND	*On-Time supply is the aspect emphasised in developing a relationship with suppliers for Body Parts manufacturing process quality (Yes: GP; No: BP-PC-2)*
THEN	*The company has considered important aspects to implement TQM for Body Parts manufacturing process quality*
OR	*The company has not considered important aspects to implement TQM for Body Parts manufacturing process quality*

The above KB rules are intended to gain information about TQM implementation. Since TQM is considered an effective approach to assure quality as well as maintenance, the absence of this approach is marked as PC-2. On the implementation, the role of employees to support TQM is the most important one thus categorised as PC-2. Meanwhile, the support of suppliers are required to ensure the quality of incoming material, thus the absence is classified as PC-3, while the quality of incoming material itself is crucial so it is marked as PC-2. Again, the variety of PC assigned to each KB rule is influenced by the importance of each aspect mentioned on certain KB rule to the system performance, particularly to the maintenance system performance.

6.5 Chapter Summary

This chapter shows the initial process to develop the conceptual design of the KBIMSO within automotive industry environment. It explains the structure of the KBIMSO model which shows the integration of GAP and AHP with KB system. Each level of the KBIMSO consists of some modules and sub-modules to obtained detailed information in order to make the recommendation as the output of KBIMSO. Those modules are complemented with process flow charts and examples of its KB rules.

One of the important steps in the design of KBIMSO model is the process of generating KB rules. The KB rules are developed based on literature review as well as discussion with academic and industrial experts. This combination produces KB rules which are required to reach a certain conclusion in a pattern of IF…THEN… statements. After that, the role of each KB rule to system performance will direct such KB rule to a certain PC level of GAP analysis. This classification will then be processed later in the AHP analysis to reach the recommendation for improvement and rectification.

The techniques and methodologies used to develop the KBIMSO application within automotive industry environment are also demonstrated in this chapter. The elements of the KB system which are important to build the KBIMSO application are *Interface Facility*, *Answer Facility*, and *Explanatory Facility*. The role of GAP is demonstrated in this chapter in term of assigning PC to each KB rule while the role of AHP analysis is presented in Chapter 8 to present the description of how these methods work simultaneously within the KB system to reach KBIMSO recommendation.

Level 0 of the KBIMSO focuses to explain company environment by identifying the company statement and the current condition of the company, thus the GAP analysis is not available on this level yet. *Level 1* and *Level 2* are directed to explore the manufacturing and business perspectives, respectively, as the strategic stage that influence maintenance decision. *Level 1 – Business Perspective* encompasses five modules to figure out the current business condition of the company, as the which are *Company Statement Analysis Module*, *Financial Analysis Module*, *Customer Analysis Module*, *Internal Business Process Analysis Module*, and *Leaning and Growth Analysis Module*. Furthermore, *Level 2 – Manufacturing Perspective* discusses manufacturing aspects which are closely related to maintenance function. Those aspects are explained in *Manufacturing Equipment Module*, *Manufacturing Process Module*, and *Process Quality Module*. In Chapter 7, Level 3, 4, and 5 discuss the *Maintenance Operations Stage* of KBIMSO which focus on maintenance perspective.

CHAPTER 7

Developing the Maintenance Operations Stage of KBIMSO

7.1 Introduction

The KBIMSO model is intended to support maintenance decision that integrates with manufacturing and business perspectives. Following the previous chapter about *Strategic Stage* of KBIMSO, this chapter focuses on *Maintenance Operations Stage*. This operational stage reflects the elements of maintenance system. This stage is not only describing the current performance of maintenance, but the KPIs on this level are also intended to specify the best improvement of maintenance aspects to fulfil the demand of manufacturing function as well as to achieve the aim of maintenance as a driver of competitive advantage.

In KBIMSO, maintenance is not only considered as a segmented function which purely works to maintain equipment availability and reliability, but it is considered in a wide perspective as a business driver to support business competitiveness. Therefore, maintenance perspective in KBIMSO is developed through three important aspects, which are maintenance rules, maintenance activities, and maintenance resources. These three aspects are then investigated to identify the KPIs for each of them which contribute to maintenance performance.

Referring again to Figure 5-20, this stage encompasses some maintenance modules as the core of KBIMSO. As if, there are three levels developed on this *Maintenance Operations Stage*, which are *Level 3 – Maintenance Rules*, *Level 4 – Maintenance Activities*, and *Level 5 – Maintenance Resources*. The particular structure of KBIMSO related to *Maintenance Operations Stage* and the flowchart of this stage can be seen in Figure 7-1 and Figure 7-2.

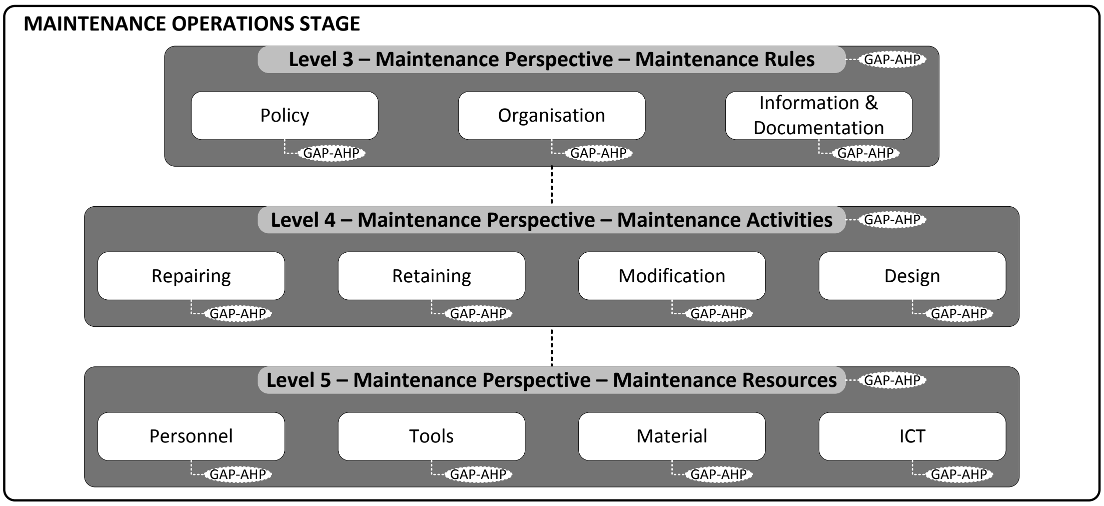


Figure 7-1 Particular structure of the KBIMSO model – Maintenance Operations Stage

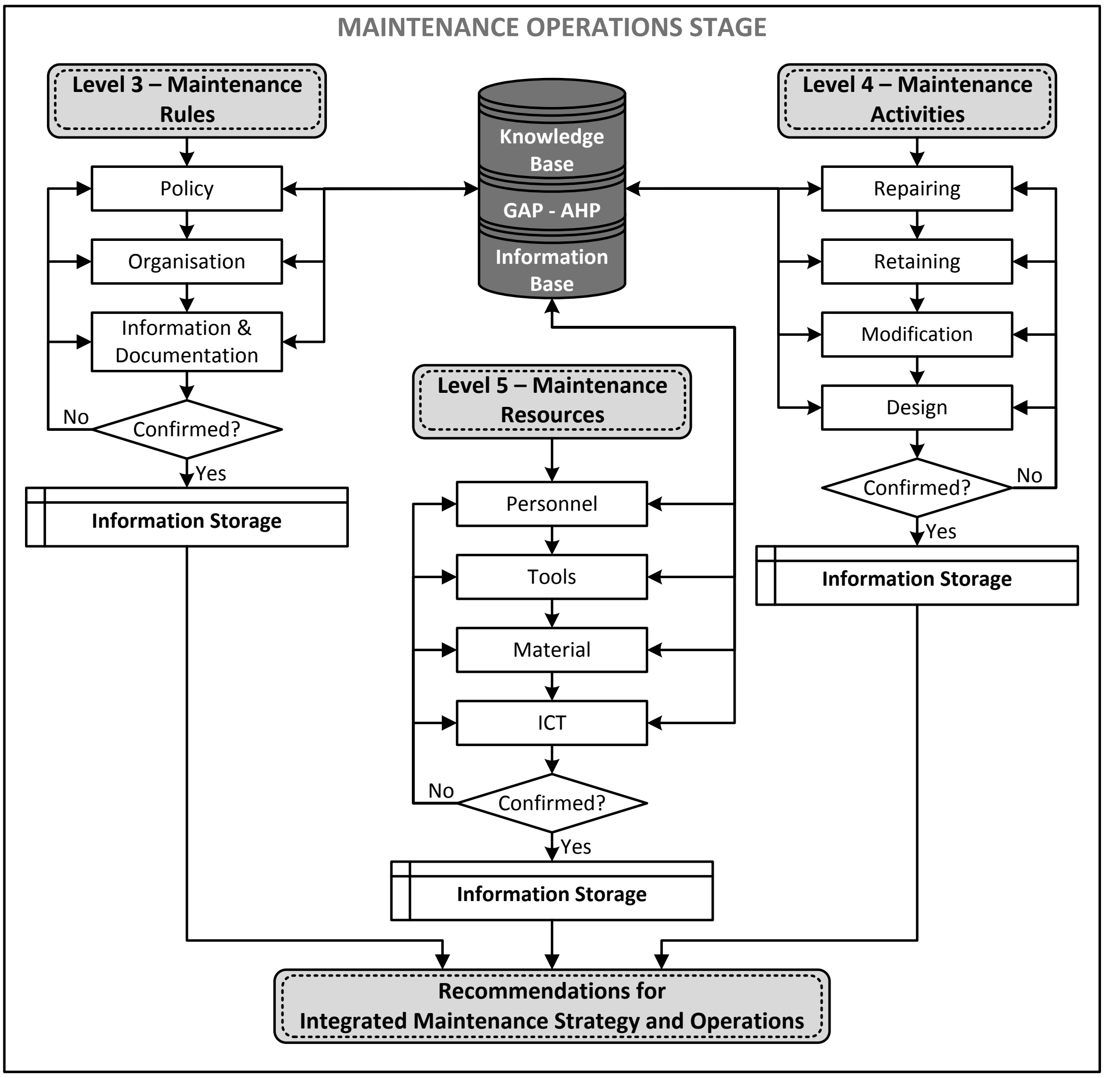


Figure 7-2 Flowchart of Maintenance Operations Stage

7.2 Level 3 – Maintenance Rules

The companies with the same resources might reach a different degree of achievement on their business performance (Hill and Hill, 2009). It is caused by a different combination of policies and cultures adapted. It could influence the exploration of resources to meet the objective. Therefore, KB rules for maintenance rules as the guideline are important to be formulated earlier before developing KB rules for maintenance activities and maintenance resources. The detailed structure of Level 3 – Maintenance Rules is shown in Figure 7-3, while the process flowchart of *Level 3 – Maintenance Rules* is presented in Figure 7-4.

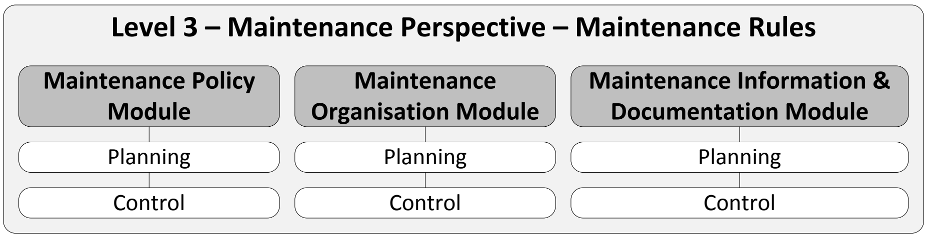


Figure 7-3 Detailed structure of Level 3 – Maintenance Rules

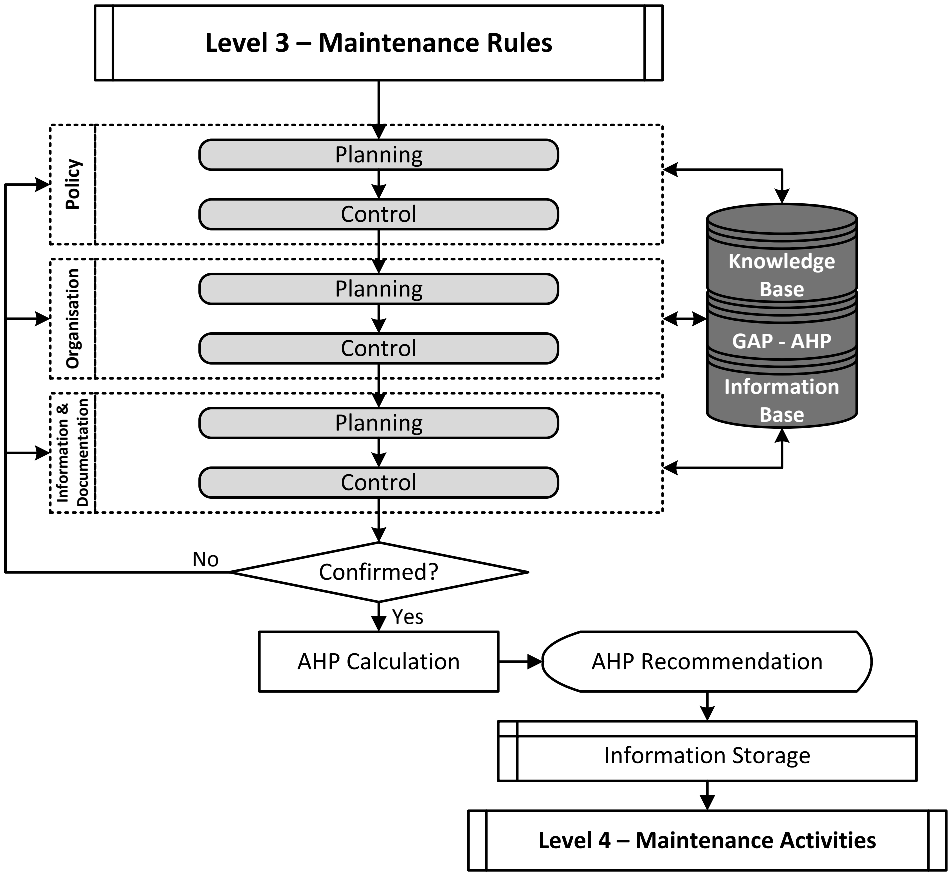


Figure 7-4 Flowchart of Level 3 – Maintenance Rules

Maintenance rules are required to support, manage and control maintenance activities and resources. These management elements cooperate with the structural and physical maintenance elements in order to achieve a successful maintenance strategy and operations (Pinjala et al., 2006). There are three modules are discussed in Level 3 – *Maintenance Rules*, which are *Maintenance Policy Module*, *Maintenance Organisation Module*, and *Maintenance Information and Documentation Module*, which are discussed in the following sections.

7.2.1 Level 3.1 – Maintenance Policy Module

Since maintenance policy is considered as a basic set of the project or a corporate guideline to manage maintenance resources and attain maintenance goals, the existence of maintenance policy is essential regardless the size of maintenance organisation (Dhillon, 2002a). It consists of courses or methods of action selected to guide and determine present and future maintenance decision (Udin, 2004). Therefore, *Maintenance Policy (MPol) Module* emphasises the contribution of different management levels, starting from creating maintenance policy until reviewing the related maintenance programmes. The process flowchart of *Maintenance Policy Module* is demonstrated in Figure 7-5.

Maintenance Policy Planning Sub-Module encompasses the important aspects required to achieve the benchmarks. The KB rules are generated to gain information about management commitment to support maintenance performance, particularly on Body Part Manufacturing Process. Started from the existence of maintenance policy, the contribution of each management level is then investigated regarding their roles to support overall maintenance performance. Besides confirming of how the maintenance policy is created, executed into maintenance programmes, and reviewed toward maintenance benchmark, the *Maintenance Policy Planning Sub-Module* also contains the KB rules about the integration of maintenance department with other departments within the organisation in order to obtain accurate information required in making maintenance decision.

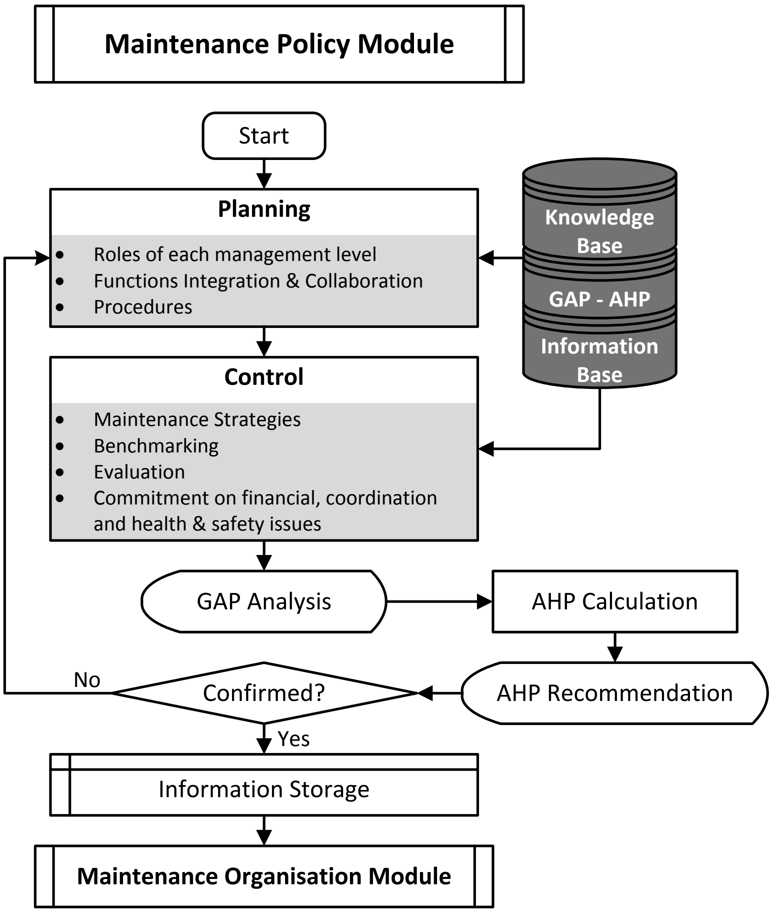


Figure 7-5 Flowchart of Level 3.1 – Maintenance Policy Module

Meanwhile, the KB rules on *Maintenance Policy Control Sub-Module* reviews the implementation of maintenance policy and its maintenance programmes on Body Part Manufacturing Process. The benchmarking approach is then used as the way to measure the achievement of maintenance performance. Therefore, there are some KPIs used to evaluate whether maintenance policy has covered required maintenance aspects to ensure that maintenance tasks can be executed as planned.

The example of generated KB rules of *Maintenance Policy Module* for *Maintenance Policy Planning Sub-Module* is illustrated as the following (only some KB rules presented):

IF *the company has policies or formal documents regarding maintenance (Yes: GP; No: PC-1)*
AND *Top Level Management is involved in creating policies (Yes: GP; No: PC-1)*
AND *Top Level Management is involved in developing policy-related plans/programmes (Yes: GP; No: PC-1)*
AND *Middle Level Management is involved in reviewing policies (Yes: GP; No: PC-1)*

AND	*Lower Level Management is involved in developing maintenance system and procedures (Yes: GP; No: PC-1)*
AND	*Lower Level Management is involved in determining performance indicators (KPIs) for performance measurement (Yes: GP; No: PC-1)*
THEN	*the company has strong policies to manage and improve maintenance performance*
OR	*the company has powerless policies to manage and improve maintenance performance*

Maintenance policies have an important role to manage maintenance activities and maintenance resources in order to achieve maintenance goal. The involvement of Top/Middle Level Management to establish maintenance policies and Lower Level Management to develop the relevant programmes are very crucial to ensure the clarity of the maintenance programmes to continually support the manufacturing process. On the set of KB rules above, the absence of any KB rule is labelled as PC-1 since those KB rules highlight some compulsory roles of management toward maintenance policies.

7.2.2 Level 3.2 – Maintenance Organisation Module

Maintenance organisation is widely discussed in term of maintenance capacity planning which includes maintenance resources of personnel, tools, materials, and ICT (Haroun and Duffuaa, 2009). Considering the dynamic of technology, process, and environment, maintenance organisation should be able to evolve and rapidly respond to any changes. A centralisation is concerned with the concentration of authority, direction, and resources from the highest level of organisation. Meanwhile, decentralisation distributes the authority and resources to the lower level of organisation in order to delegate responsibility to the point of action as close as possible. The degree of centralisation could be different among organisations. In some cases, the mixed system is chosen by the organisation which enables some decentralised maintenance units to be linked to central maintenance unit (Duffuaa et al., 1999). The process flowchart of *Maintenance Organisation (MOrg) Module* is demonstrated in Figure 7-6.

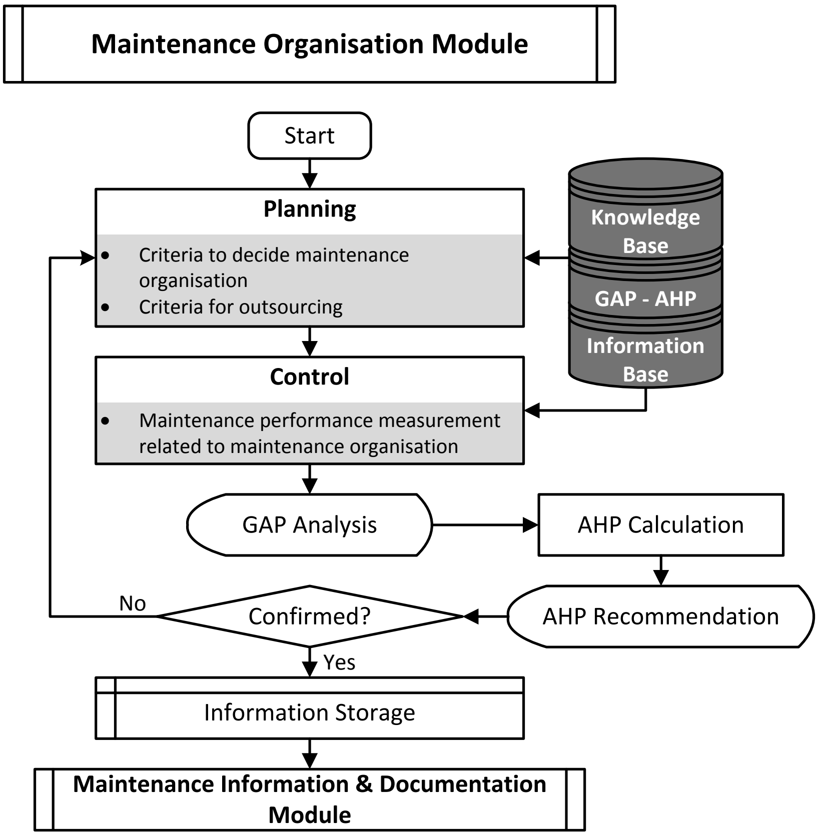


Figure 7-6 Flowchart of Level 3.2 – Maintenance Organisation Module

The first KB rules highlighted in the *MOrg Planning Sub-Module* are that the organisation has been considering maintenance organisation criteria to execute maintenance activities. Maintenance organisation could be arranged on maintenance personnel skills and numbers, maintenance tools and equipment, maintenance spare parts, maintenance load, size of the plant, and so on (Duffuaa et al., 1999). A correct decision of maintenance organisation selection leads to improve maintenance performance.

In case the maintenance department cannot handle all requested tasks due to its limitation of resources, outsourcing could be considered as the solution. To get the optimal benefit of outsourcing, the organisation should only take outsourcing when the requirements are fulfilled, such as when in-house maintenance capacity is not sufficient to carry out expected maintenance tasks, or expected volume of maintenance tasks is too small but the variety of maintenance-related specialist skills is too wide to provide in-house maintenance personnel. When outsourcing is taken under appropriate requirements, the maintenance function can perform optimally to meet manufacturing and quality functions needs.

The example of generated KB rules of the *Maintenance Organisation Module* for *MOrg Planning Sub-Module* is illustrated as the following (only some KB rules presented):

IF	*In-house maintenance capacity is not sufficient to carry out expected maintenance tasks (Yes: GP; No: BP-PC-2)*
AND	*Expected volume of maintenance tasks is too small and the variety of maintenance-related specialist skills is too wide to provide in-house maintenance personnel (Yes: GP; No: BP-PC-4)*
AND	*Work for which the skill of specialists is required on a routine basis and which is readily available in the market on a competitive basis (Yes: GP; No: BP-PC-4)*
AND	*Outsourcing is cheaper than recruiting in-house maintenance personnel (Yes: GP; No: BP-PC-4)*
AND	*There is an agreement with equipment manufacturer (Yes: GP; No: BP-PC-6)*
THEN	*The company has considered relevant reasons to take outsourcing decision*
OR	*The company need to review its outsourcing decision based on relevant reasons*

In this KBIMSO, KB rules translate and elaborate the KPIs into clear rules. Therefore, the company can assess the maintenance performance and identify the priority factor to be rectified at the first place in order to get a significant performance improvement. The priority of KB rules varies based on the importance of each condition to the system performance. On the set of KB rules above, the condition when in-house maintenance capacity is not sufficient to carry out expected maintenance tasks is very crucial and potentially delay manufacturing process that influences the system performance. This KB rule is then categorised as PC-2. But when the decision of outsourcing is taken because of the agreement with the equipment manufacturer, the impact is less crucial to the system, since it is a part of the procurement contract. In this situation, the absence of such KB rule is classified as PC-6.

7.2.3 Level 3.3 – Maintenance Information and Documentation Module

Maintenance work order includes maintenance planning, maintenance scheduling, and maintenance control (Duffuaa et al., 1999). To smooth the process, there are information and documentation needed. To ease documenting and retrieving the required information, the company usually has a maintenance information system to support maintenance function. The KBIMSO model has *Maintenance Information and Documentation (MID) Module* within the

Maintenance Rules Level as one important tool for the maintenance department to run maintenance activities with available maintenance resources. The process flowchart of *Maintenance Information and Documentation Module* is demonstrated in Figure 7-7.

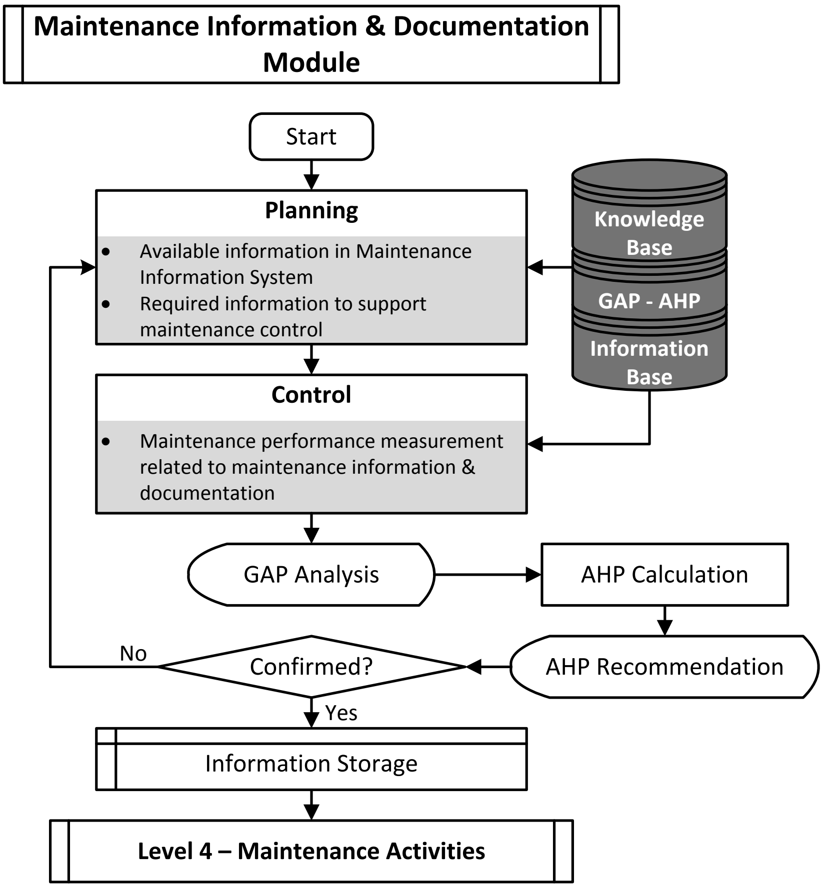


Figure 7-7 Flowchart of Level 3.3 – Maintenance Information and Documentation Module

Basic information that should be available within maintenance information system is taken from maintenance department itself and other departments which can provide related information to execute maintenance tasks. The information about a person or department requesting the work, work identification and description, skill required, tools required, spare parts required, and so on, are necessary to identify workload and allocated resources. After the above information, maintenance also needs to provide details of current equipment performance such as *Mean Time to Failure* (MTTF), *Mean Time Between Failure* (MTBF), *Mean Time to Repair* (MTTR), etc. These supporting documents and information are required to guide maintenance operators in performing their tasks and taking correct treatment to ensure that manufacturing equipment can perform on its designated performance. Furthermore, the details of this information and documentation are represented through KB rules on *MID Planning Sub-Module*.

The critical point in information and documentation is accuracy and accessibility, which is discussed in *MID Control Sub-Module*. There is no point to have a big amount of information unless it is up-to-date and accessible. Moreover, synchronised and integrated documents with the organisation information system will ease people to retrieve the information related to their work.

The example of generated KB rules of the *Maintenance Information and Documentation Module* for *MID Planning Sub-Module* is illustrated as the following (only some KB rules presented):

IF	*Maintenance Information System contains inventory number, unit description, and site (Yes: GP; No: BP-PC-1)*
AND	*Maintenance Information System contains work description and standard time to complete the task (Yes: GP; No: BP-PC-1)*
AND	*Maintenance Information System contains work priority and work due date (Yes: GP; No: BP-PC-1)*
AND	*Maintenance Information System contains spare parts required (Yes: GP; No: BP-PC-1)*
AND	*Maintenance Information System contains tools required (Yes: GP; No: BP-PC-1)*
AND	*Maintenance Information System contains maintenance resources availability (Yes: GP; No: BP-PC-1)*
THEN	*The company has included the important information into the Maintenance Information System*
OR	*The company has not included the important information into the Maintenance Information System*

The set of KB rules above details the required information to support maintenance planning, scheduling and control. The existence of information is crucial to provide a seamless maintenance planning and operation, thus categorised as PC-1. Else, the absence of any information will cause maintenance function produce incorrect schedule and recommendation.

7.3 Level 4 – Maintenance Activities

Maintenance activity is defined as a set of technical process on both manufacturing and maintenance environments to ensure manufacturing equipment can meet its expected performance in acceptable business recommendation during their whole commercial life cycles (Liyanage, 2007). The detailed structure of *Level 4 – Maintenance Activities* is shown in Figure 7-8, while the process flowchart of *Level 4 – Maintenance Activities* is presented in Figure 7-9.

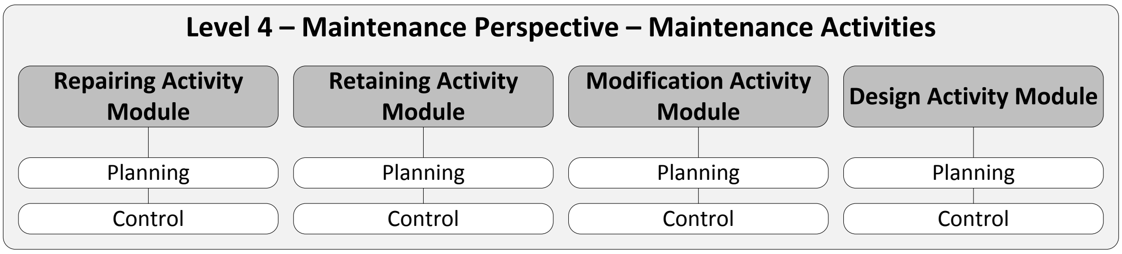


Figure 7-8 Detailed structure of Level 4 – Maintenance Activities

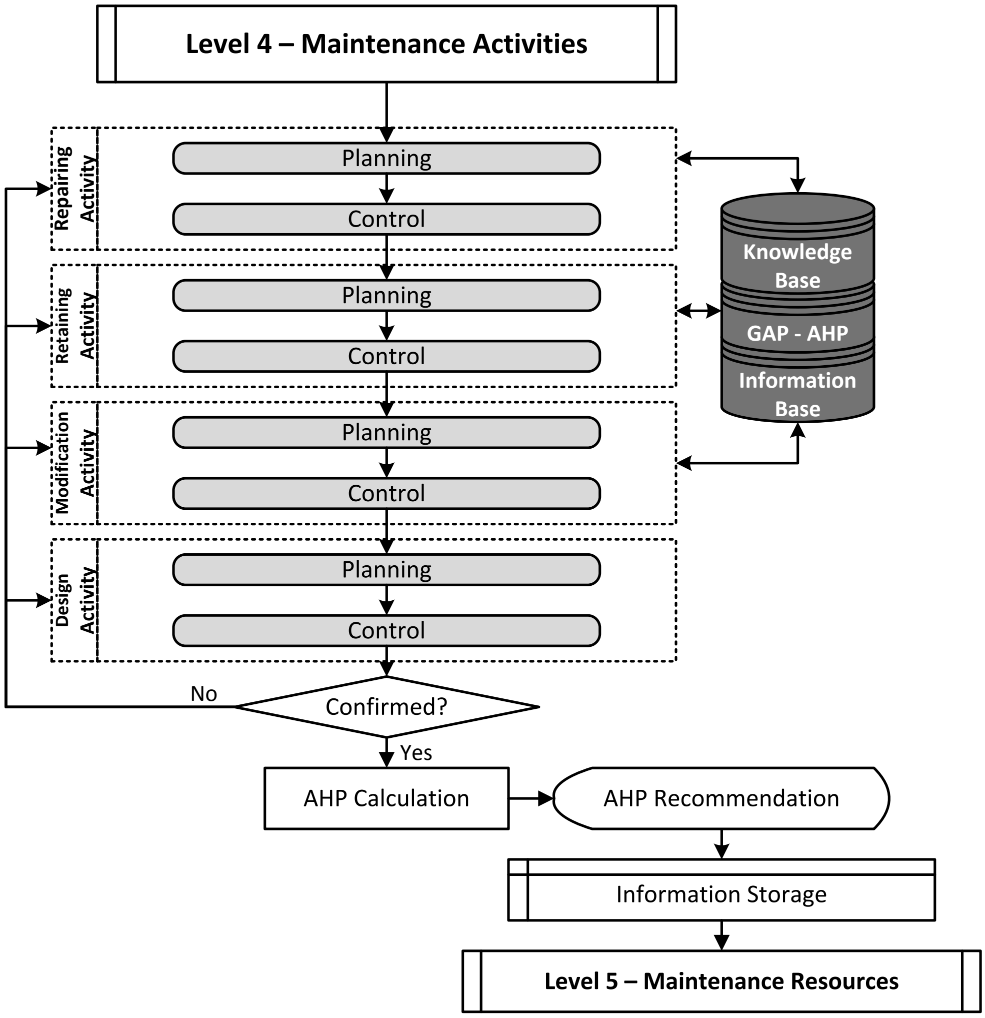


Figure 7-9 Flowchart of Level 4 – Maintenance Activities

Maintenance Activities Level in the KBIMSO encompasses four modules which represent four main maintenance activities – *Repairing*, *Retaining*, *Modification*, and *Design Activities*. As can be seen in the flowchart of *Level 4 - Maintenance*

Activities, each module contains two sub-modules, *Planning* and *Control Sub-Modules*. The same grouping of sub-modules within modules is beneficial to ease categorisation in comparing and making the recommendation on the next step of KBIMSO model.

The maintenance activities are descended from maintenance policy formulated in Section 2.4 and illustrated in Figure 2-2. By assuming that the company involved in implementing KBIMSO model is a company which has considered the importance of maintenance and it counts maintenance as an organisation vital function which contributes to business success, maintenance activities are defined in the context of planned maintenance. *Repairing Activity Module* refers to Corrective Maintenance as responses to planned and scheduled Preventive and Predictive Maintenance. By this, repairing activity due to unplanned and unscheduled Corrective Maintenance is not considered in KBIMSO model. *Retaining Activity Module* refers to the regular practice of Preventive Maintenance (Time-Based Management and Run-Based Management) and Predictive Maintenance (Condition-Based Maintenance). Meanwhile, *Modification Activity* and *Design Activity* refer to Aggressive Maintenance as a derivation of Total Productive Maintenance. A detailed explanation of each maintenance activity in KBIMSO is discussed in the following sections.

7.3.1 Level 4.1 – Repairing Activity Module

Traditional thought of maintenance considers that maintenance is the fire-fighting and unplanned reaction which is only intended to correct and repair any malfunction of manufacturing equipment (Smith and Hinchcliffe, 2004). Yet, the current thought of maintenance as the competitive driver for the business organisation then put repairing activity as the part of planned maintenance. By this, the deterioration has been obviously detected and the repairing of equipment is part of planned and scheduled maintenance (Gulati, 2013). Repairing activity mentioned in KBIMSO model is indented as the follow-up actions after monitoring equipment condition. It is carried out as the remedial action due to failure or deficiencies discovered during Preventive Maintenance and Predictive Maintenance. The process flowchart of *Repairing Activity (RepA) Module* is demonstrated in Figure 7-10.

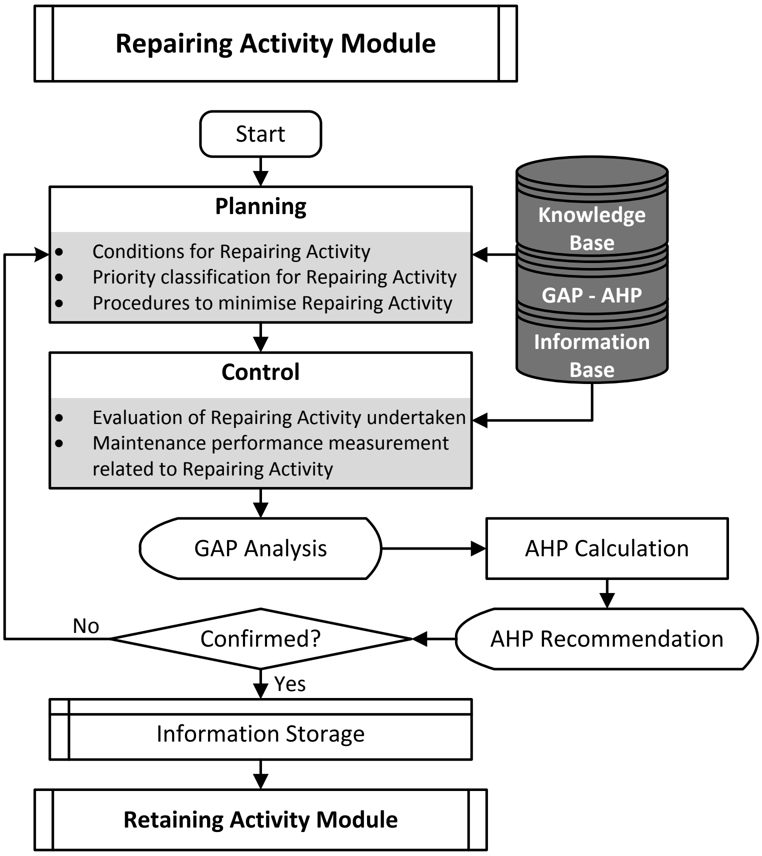


Figure 7-10 Flowchart of Level 4.1 – Repairing Activity Module

Repairing Activity Module consists of two sub-modules, *RepA Planning Sub-Module* and *RepA Control Sub-Module*. In *RepA Planning Sub-Module*, the KB rules are generated to figure out how repairing activity is conducted in a maintenance environment. Repairing activity is directed to deal with the risk and loss, thus the repairing activity should consider priority, procedure, and cost efficiency (Dhillon, 2002b). Moreover, effective repairing activity can be carried out as a comparative decision between risk and cost of failure as well as the cost of maintenance needed to mitigate such risk and failure (Dhillon, 2002b). Therefore, the KBIMSO model reminds the company through KB rules that taking repairing activity based on priority is compulsory to minimise cost and failure. The procedures are then developed to different situations when repairing activity is needed.

Meanwhile, *Repairing Activity Control Sub-Module* is equipped with KB rules to investigate the maintenance practice of the company related to this activity based on planned and scheduled corrective maintenance. When documentation of repairing activity is explored, it can be seen whether the reasons for the company to conduct repairing activity already based on modern maintenance concept as a business driver.

The example of generated KB rules of the *Repairing Activity Module* for *Repairing Activity Control Sub-Module* is illustrated as the following (only some KB rules presented):

IF *The deterioration of equipment has been detected earlier (Always (> 80%): GP; Frequently (60 - 85%): BP-PC-5, Sometimes (40 - 60%): BP-PC-4, Occasionally (25 - 40%): BP-PC-3, Rarely (< 25%): BP-PC-2)*

AND *The equipment is repaired after its expected lifetime (Always (> 80%): GP; Frequently (60 - 85%): BP-PC-5, Sometimes (40 - 60%): BP-PC-4, Occasionally (25 - 40%): BP-PC-3, Rarely (< 25%): BP-PC-2)*

AND *The equipment is repaired just before the functional failure (Always (> 80%): GP; Frequently (60 - 85%): BP-PC-5, Sometimes (40 - 60%): BP-PC-4, Occasionally (25 - 40%): BP-PC-3, Rarely (< 25%): BP-PC-2)*

AND *The equipment is repaired due to run-to-failure approach (Always (> 80%): GP; Frequently (60 - 85%): BP-PC-5, Sometimes (40 - 60%): BP-PC-4, Occasionally (25 - 40%): BP-PC-3, Rarely (< 25%): BP-PC-2)*

AND *The action of repairing is part of planned maintenance schedule (Always (> 80%): GP; Frequently (60 - 85%): BP-PC-5, Sometimes (40 - 60%): BP-PC-4, Occasionally (25 - 40%): BP-PC-3, Rarely (< 25%): BP-PC-2)*

AND *The action of repairing is done by the planned maintenance resources (Always (> 80%): GP; Frequently (60 - 85%): BP-PC-5, Sometimes (40 - 60%): BP-PC-4, Occasionally (25 - 40%): BP-PC-3, Rarely (< 25%): BP-PC-2)*

THEN *The maintenance repairing activity is applied effectively*

OR *The maintenance repairing activity is not applied effectively*

The requirement for taking repairing activity above can explain whether the company has executed effective repairing activity. The presence of all pre-requisite conditions on those KB rules means the action of repairing is under schedule and can be managed appropriately. On the other hand, the absence of pre-requisite conditions is rated as PC-1, which imply a very serious problem in a short period of time. It means that the company cannot manage its planned and scheduled maintenance appropriately which cause repairing activity is mostly directed as the fire-fighter action.

7.3.2 Level 4.2 – Retaining Activity Module

The retaining activity is rooted from the thought that maintenance function is not only about fixing the failure. Retaining activity accommodates both Preventive Maintenance and Predictive Maintenance. Lack of performing retaining activity will cause losses and inefficiency and lead to bad business performance. The process flowchart of *Retaining Activity (RetA) Module* is shown in Figure 7-11.

The basic maintenance procedure for retaining activity is involving manufacturing operators to maintain manufacturing equipment under their responsibility on daily basis and to monitor any potential failure to get maintenance treatment in advance. Those basic maintenance tasks include inspection, lubrication, calibration, testing, alignment, adjustment, etc. (Dhillon, 2002a). Moreover, Root Cause Analysis (RCA) has the procedures to systematically identify potential failure and to propose a solution. Maintenance department also needs to establish maintenance assignment frequency to map maintenance treatment required for the equipment. The variety of retaining activity above is then translated into KB rules in *RetA Planning Sub-Module*.

RetA Control Sub-Module is intended to assess the effectiveness of retaining activity as part of Preventive and Predictive Maintenance through related indicators. The evaluation could help the company to evaluate particular maintenance performance in order to take improvement and rectification plan.

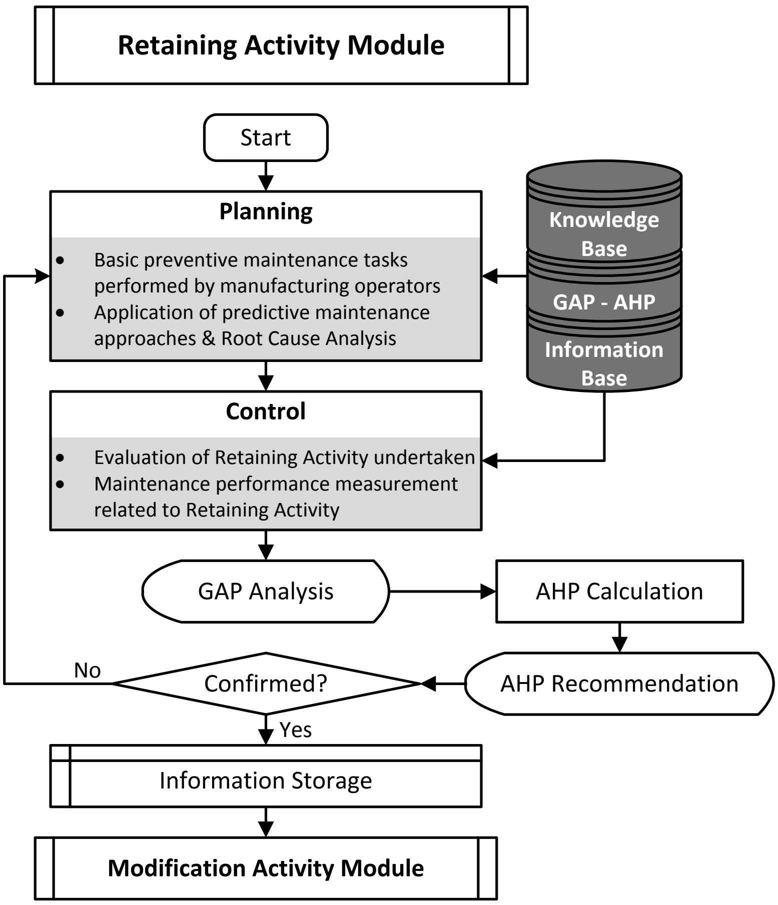


Figure 7-11 Flowchart of Level 4.2 – Retaining Activity Module

The example of generated KB rules of the *Retaining Activity Module* for *Retaining Activity Planning Sub-Module* is illustrated as the following (only some KB rules presented):

IF *Basic maintenance task of inspection is performed by the Body Part Manufacturing operator (Yes: GP; No: BP-PC-3)*
AND *Basic maintenance task of servicing is performed by the Body Part Manufacturing operator (Yes: GP; No: BP-PC-3)*
AND *Basic maintenance task of calibration is performed by the Body Part Manufacturing operator (Yes: GP; No: BP-PC-3)*
AND *Basic maintenance task of testing is performed by the Body Part Manufacturing operator (Yes: GP; No: BP-PC-3)*
AND *Basic maintenance task of alignment is performed by the Body Part Manufacturing operator (Yes: GP; No: BP-PC-3)*
AND *Basic maintenance task of adjustment is performed by the Body Part Manufacturing operator (Yes: GP; No: BP-PC-3)*
THEN *Basic preventive maintenance tasks have been supported by the Body Part Manufacturing operator*
OR *Basic preventive maintenance tasks have not been fully supported by Body Part Manufacturing operator*
OR *Basic preventive maintenance tasks have not been supported at all by the Body Part Manufacturing operator*

The KB rules presented above refer to basic maintenance tasks that could be performed by manufacturing operators. All of them are categorised as PC-3. It means that the presence of those KB rules will apparently contribute to improving system performance. Instead, the absence of this rules indicates poor work culture and will increase maintenance workload. This condition will lead to ineffective maintenance performance and will impact overall business performance after a period of time.

7.3.3 Level 4.3 – Modification Activity Module

The key of modification activity is to bring a particular equipment to its acceptable condition through coordination among engineering and other departments within the organisation (Duffuaa et al., 1999). Modification activity supports maintenance function through continuous improvement by practising a continuous process of improvement, using feedback and communications to ensure that changes in design/procedures are efficiently made (Dhillon, 2002b). It is known as part of Aggressive Maintenance or Proactive Maintenance.

Modification Activity (MoA) Sub-Module (together with *Design Activity Sub-Module* which is discussed in the next section) is generated from Total Productive

Maintenance (TPM). TPM is a resource-based maintenance management system with a strong focus on people and plays as the subsequent step to extend the benefits of the Total Quality Management (TQM) (Simões et al., 2015). It is considered as the effective maintenance strategy to integrate maintenance strategy with manufacturing and other related functions. The process flowchart of *Modification Activity Module* is shown in Figure 7-12.

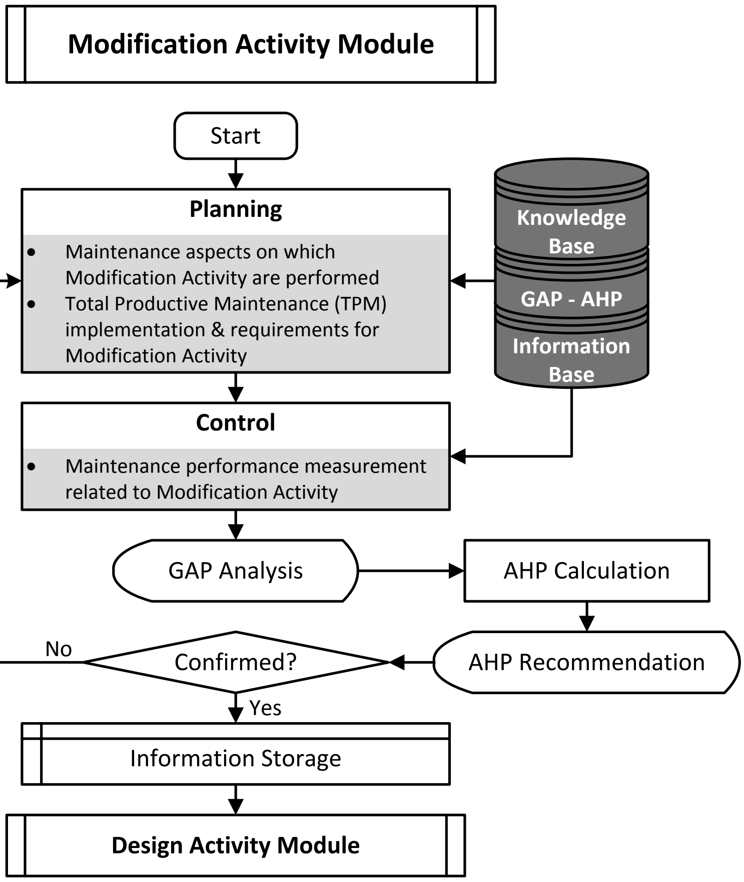


Figure 7-12 Flowchart of Level 4.3 – Modification Activity Module

Modification Activity Planning Sub-Module emphasises the potential aspects of maintenance that could perform modification activity. Besides, KB rules can explore implemented TPM culture to conduct TPM approach. The performance of maintenance in implementing this activity is then reviewed in *Modification Activity Control Sub-Module*.

The example of generated KB rules of the *Modification Activity Module* for *Modification Activity Planning Sub-Module* is illustrated as the following (only some KB rules presented):

IF	*The company considers that Modification Activity as part of its maintenance activities (Yes: GP; No: BP-PC-3)*
AND	*Modification Activity is performed in equipment design (Yes: GP; No: BP-PC-5)*
AND	*Modification Activity is performed in workmanship (Yes: GP; No: BP-PC-5)*
AND	*Modification Activity is performed in equipment installation (Yes: GP; No: BP-PC-5)*
AND	*Modification Activity is performed in maintenance scheduling (Yes: GP; No: BP-PC-5)*
AND	*Modification Activity is performed in maintenance procedures (Yes: GP; No: BP-PC-5)*
THEN	*Modification Activity has been implemented in many maintenance aspects*
OR	*Modification Activity has been implemented in a few maintenance aspects*
OR	*Modification Activity has not been implemented in any maintenance aspects*

The presence of modification activities in different aspect within maintenance function represents that the company has a concern about aggressive/pro-active maintenance. Coordination of different functions is required as the driver to maintain certain equipment within its acceptable performance. However, this activity has not widely considered as the main maintenance activity compared to repairing and retaining activity. Therefore, the absence of any KB rule is categorised PC-5. It indicated that their absence could be substituted by other activities, yet their presence will contribute to support continuous improvement.

7.3.4 Level 4.4 – Design Activity Module

Design activity is generated from the same approach with modification activity, which is aggressive maintenance that is derived from Total Productive Maintenance (TPM). Therefore, the KB rules generated for *Design Activity Module* is similar to *Modification Activity Module*. The segregation between these two activities is intended to avoid any ambiguity on KBIMSO in order to reach conclusion and make a recommendation and to emphasise which TPM activity that the company has put its concern on. The process flowchart of is *Design Activity Module* demonstrated in Figure 7-13.

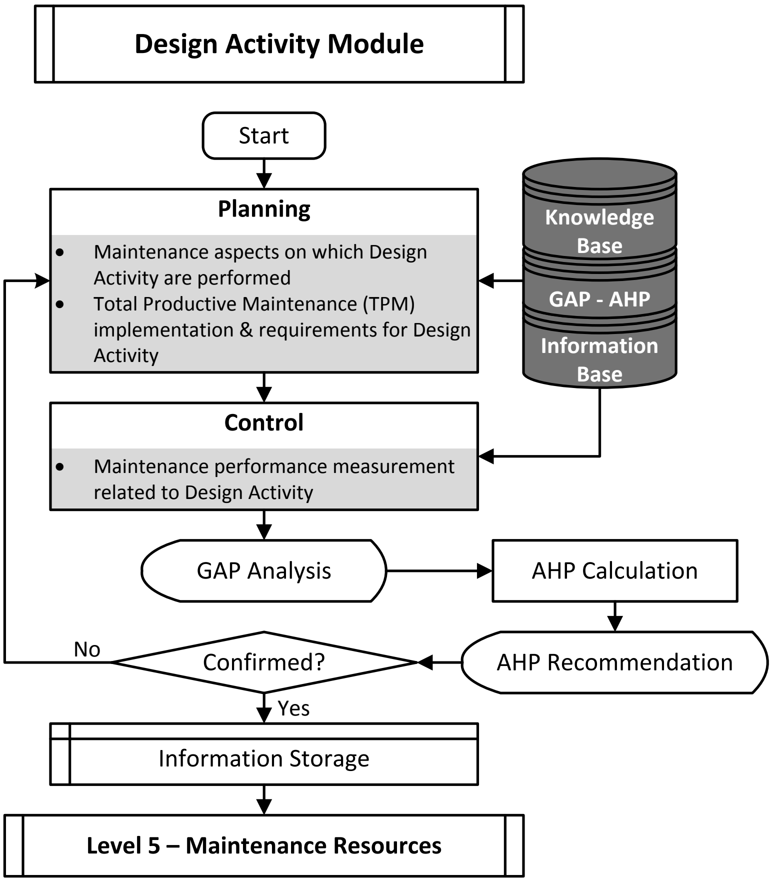


Figure 7-13 Flowchart of Level 4.4 – Design Activity Module

The example of generated KB rules of the *Design (DeA) Activity Module* for *Design Activity Control Sub-Module* is illustrated as the following (only some KB rules presented):

IF *The maintenance performance when performing Design Activity in term of reducing downtime is: Excellent (> 80%): GP; Good (60 - 85%): BP-PC-5, Fair (40 - 60%): BP-PC-4, Poor (25 - 40%): BP-PC-3, Worse (< 25%): BP-PC-2*

AND *The maintenance performance when performing Design Activity in term of improving equipment effectiveness is: Excellent (> 80%): GP; Good (60 - 85%): BP-PC-5, Fair (40 - 60%): BP-PC-4, Poor (25 - 40%): BP-PC-3, Worse (< 25%): BP-PC-2*

AND *The maintenance performance when performing Design Activity in term of improving productivity is: Excellent (> 80%): GP; Good (60 - 85%): BP-PC-5, Fair (40 - 60%): BP-PC-4, Poor (25 - 40%): BP-PC-3, Worse (< 25%): BP-PC-2*

AND *The maintenance performance when performing Design Activity in term of improving workplace safety and environment issues is: Excellent (> 80%): GP; Good (60 - 85%): BP-PC-5, Fair (40 - 60%): BP-PC-4, Poor (25 - 40%): BP-PC-3, Worse (< 25%): BP-PC-2*

AND *The maintenance performance when performing Design Activity in term of eliminating production losses is: Excellent (> 80%): GP; Good (60 - 85%): BP-PC-5, Fair (40 - 60%): BP-PC-4, Poor (25 - 40%): BP-PC-3, Worse (< 25%): BP-PC-2*

AND	*The maintenance performance when performing Design Activity in term of maximising Overall Equipment Effectiveness (OEE) is: Excellent (> 80%): GP; Good (60 - 85%): BP-PC-5, Fair (40 - 60%): BP-PC-4, Poor (25 - 40%): BP-PC-3, Worse (< 25%): BP-PC-2*
THEN	*The Design Activity is performed well and supported by the organisation*
OR	*The Design Activity is not performed well and is not fully supported by the organisation*

KB rules on *Design Activity Control Sub-Module* are directed to review the implementation of design activity within maintenance function. Ideally, when the company has successfully implemented aggressive maintenance, either modification or design activity, the performance of each maintenance variable stated above is ranked excellent (Good Point/GP). In return, the KBIMSO model concludes that the design activity is performed well and supported by the organisation. Instead, the maintenance variable is categorised as Bad Point, ranging from PC-2 to PC-5. It means that the design activity is not fully performed well and requires more attention.

7.4 Level 5 – Maintenance Resources

Maintenance resources contribute as one of the key decisions in maintenance strategy implementation (Hayes et al., 2005). Managers deal with many factors such as tight budgets, resource sharing, limited availability of specially skilled personnel, and shifting priorities which require the solution of priorities, conflict, creativity, planning and power struggles (Dhillon, 2002). Trade-offs is one option to deal with resources limitation and resources allocation with respect to business strategy. Therefore, the optimal maintenance service might be achieved by setting priorities on tasks, resources, as well as their impacts on manufacturing performance. For that reasons, the KBIMSO model includes maintenance resources into KBIMSO framework considering its role in maintenance performance. The detailed structure of Level 4 is shown in Figure 7-14.

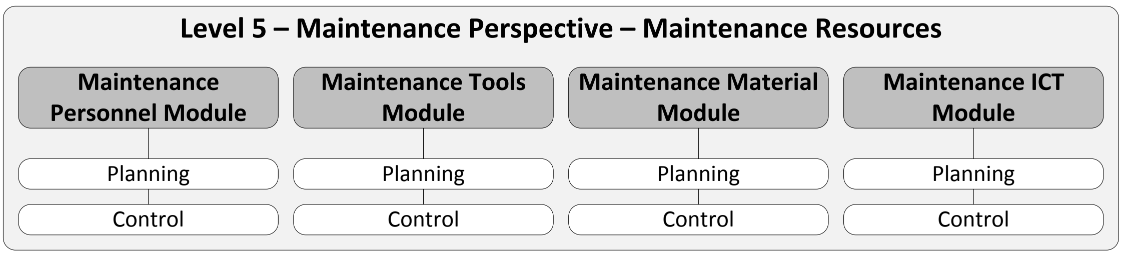


Figure 7-14 Detailed structure of Level 5 – Maintenance Resources

Maintenance Resources Level encompasses four modules; *Maintenance Personnel, Tools, Material, and ICT Modules*. Each module contains two sub-modules; *Planning* and *Control*. *Planning Sub-Module* focuses on the core aspects required to achieve the benchmarks, while *Control Sub-Module* focuses on evaluating the achievements and proposing the improvement plan. The process flowchart of *Level 5 – Maintenance Resources* is presented in Figure 7-15.

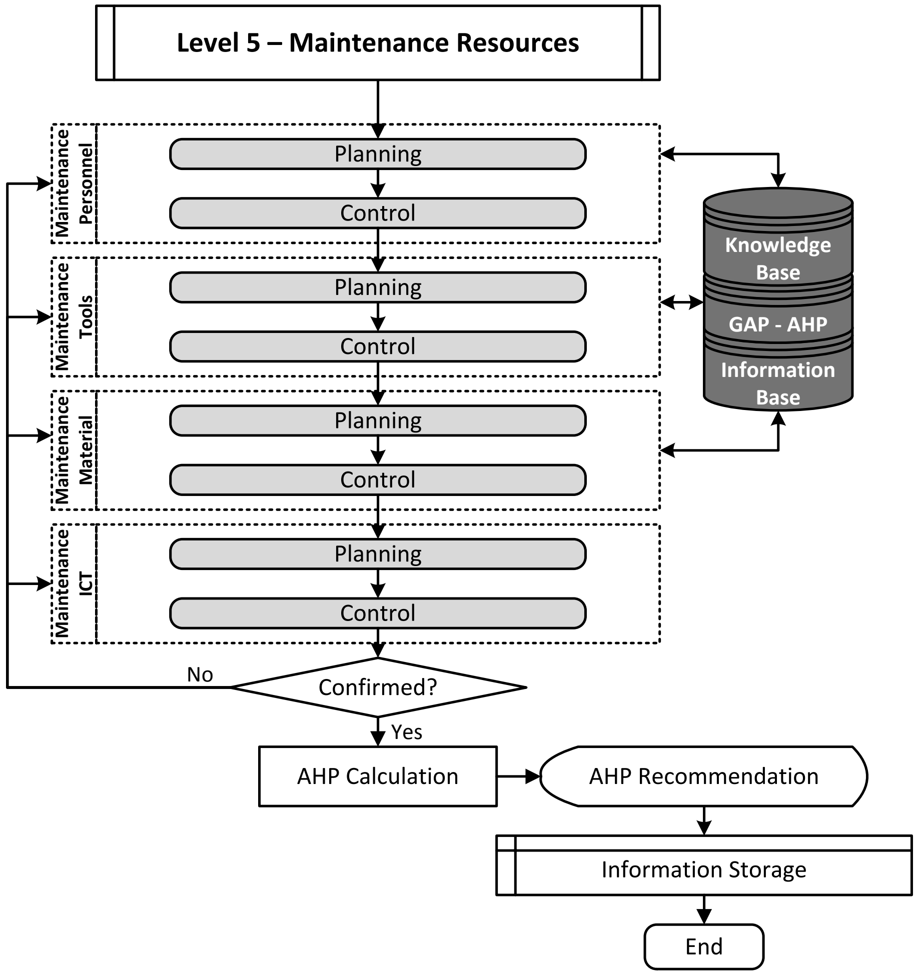


Figure 7-15 Flowchart of Level 5 – Maintenance Resources

The KB rules are generated regarding important aspect identified on each sub-module. At the next step after collecting response of KB rules from all modules, KBIMSO model provides a recommendation to improve maintenance performance in term of maintenance resources.

7.4.1 Level 5.1 – Maintenance Personnel Module

Human is the system entity who has dynamic performance and specific needs thus need to be treated specially. To produce the best performance, their needs must be managed and fulfilled. Therefore, managing maintenance personnel could encompass task performance, citizenship performance, and counterproductive performance (DuBrin, 2010). The process flowchart of *Maintenance Personnel Module* is demonstrated in Figure 7-16.

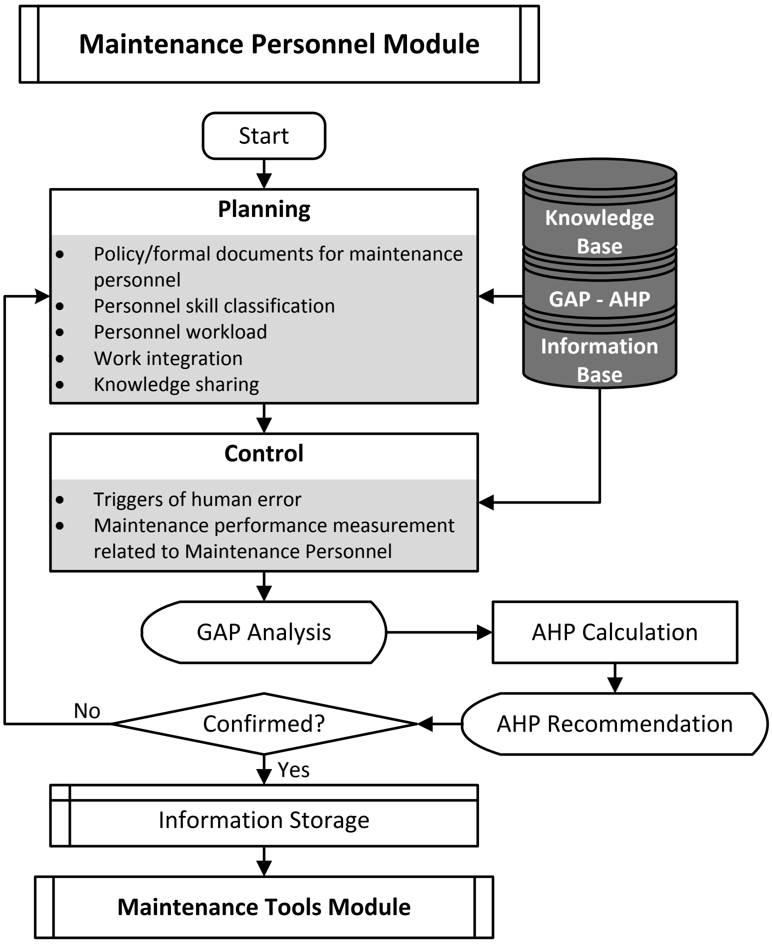


Figure 7-16 Flowchart of Level 5.1 – Maintenance Personnel Module

Different from *Employee Engagement Sub-Module* as part of *Learning and Growth Analysis Module* in *Level 1 – Business Perspective*, which specifically discusses the aspects required to achieve employee satisfaction in a business perspective, *Maintenance Personnel Module* focuses the intention of the company to maintain the work environment for the maintenance personnel so they can work based on their skill and on reasonable workload. Initial step to manage maintenance personnel is done by providing an adequate policy to ensure that the maintenance personnel has realistic tasks allocated based on their skills and competencies, time, and rational workload. As the front-liners on executing maintenance tasks, maintenance personnel need to communicate with different departments for completing their job as well as for knowledge sharing. This approach will increase their know-how to rapidly deal with any maintenance-related problem.

The example of generated KB rules of the *Maintenance Personnel Module* for *Maintenance Personnel Planning Sub-Module* is illustrated as the following (only some KB rules presented):

IF	*the maintenance personnel are classified based on formal education background (Yes: GP; No: PC-3)*
AND	*the maintenance personnel are classified based on professional training certification (Yes: GP; No: PC-3)*
AND	*the maintenance personnel are classified based on internal performance appraisal (Yes: GP; No: PC-3)*
AND	*the company considers shift pattern to assign maintenance personnel workload (Yes: GP; No: PC-3)*
AND	*the company considers workload safety to assign maintenance personnel workload (Yes: GP; No: PC-3)*
AND	*the company considers team capability to assign maintenance personnel workload (Yes: GP; No: PC-3)*
THEN	*the company has a strong commitment to manage and improve maintenance personnel performance*
OR	*the company has no commitment to manage and improve maintenance personnel performance*

The KB rules presented above give the guideline of how the company classifies its maintenance personnel in order to allocate maintenance resources and set their workload. The absence of each KB rule above is categorised as PC-3. It indicates a quite major problem, which is most likely to have pre-requisite to the system and may impact overall system performance after a period of time.

7.4.2 Level 5.2 – Maintenance Tools Module

Maintenance tool is defined as the equipment required for maintenance function to complete maintenance tasks. Providing tools in stock for a predicted interval is mostly chosen when the risk of unavailable tools is higher (Duffuaa et al., 1999). Therefore, *Maintenance Tools Module* is included in *Level 5 – Maintenance Resources*, with the process flowchart is presented in Figure 7-17.

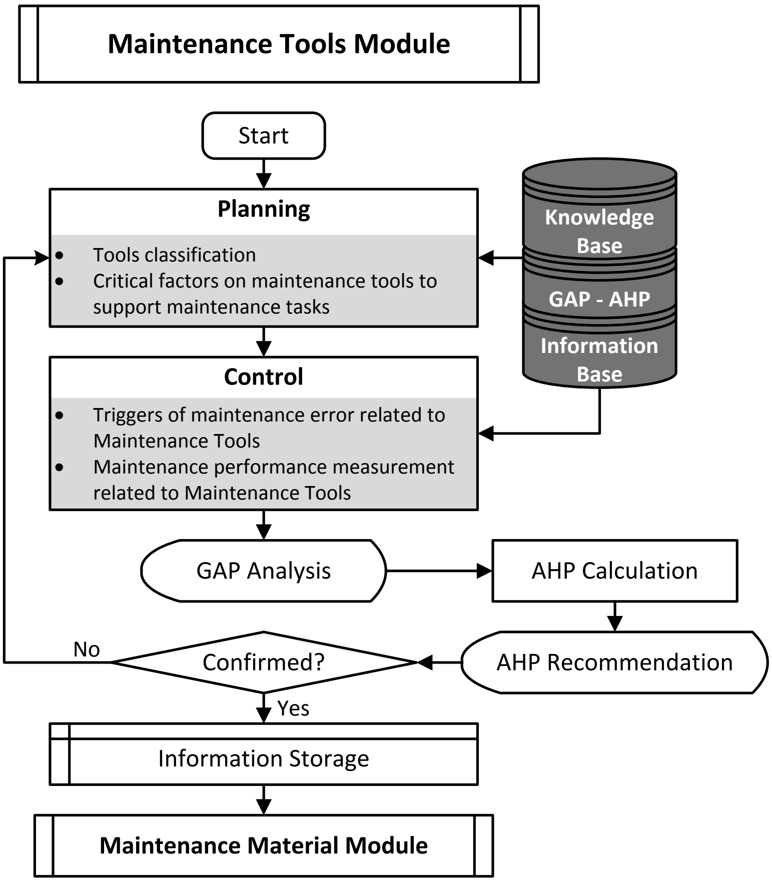


Figure 7-17 Flowchart of Level 5.2 – Maintenance Tools Module

Maintenance Tools Planning Sub-Module highlights the importance of tools classification to get priority of maintenance tools in stock. The classification will help to decide the quantity of stock, reorder time, holding treatment, etc. The absence of classifying tools correctly may cause either deficit or oversupply which will impact maintenance cost and downtime. Besides, there are some critical aspects should be maintained regarding maintenance tools in order to ensure accuracy and availability of maintenance tools to support maintenance tasks. *Maintenance Tools Control Sub-Module* is then conducted to check the frequency of particular maintenance error due to maintenance tools mismanagement.

The example of generated KB rules of the *Maintenance Tools Module* for *Maintenance Tools Planning Sub-Module* is illustrated as the following (only some KB rules presented):

IF *Calibration is maintained regularly as a critical factor for maintenance tools (Yes: GP; No: BP-PC-2)*
AND *Compatibility is maintained regularly as a critical factor for maintenance tools (Yes: GP; No: BP-PC-2)*

AND *Availability is maintained regularly as a critical factor for maintenance tools (Yes: GP; No: BP-PC-2)*
AND *The maintenance department has a classification of maintenance tools in term of tools value (price) (Yes: GP; No: BP-PC-3)*
AND *The maintenance department has a classification of maintenance tools in term of tools speciality (Yes: GP; No: BP-PC-3)*
AND *The maintenance department has a classification of maintenance tools in term of tools criticality (Yes: GP; No: BP-PC-3)*
THEN *Maintenance department has provided the required treatments to support maintenance tools performance*
OR *Maintenance department has not fully provided the required treatments to support maintenance tools performance*

Calibration, compatibility, and availability of maintenance tools are very critical to overall maintenance performance. The absence of such factors is categorised as PC-2 since it can significantly influence the completion of maintenance tasks in term of time and output. Meanwhile, the rest of KB rules are classified as PC-3 since their absences indicate inaccuracy of maintenance tools classification which could cause inefficiency.

7.4.3 Level 5.3 – Maintenance Material Module

Maintenance Material Module is derived from inventory control approach which aims to maintain maintenance spares and materials at the desired level in order to minimise the cost of holding inventory and minimise the cost of spare unavailability (Duffuaa et al., 1999). In the KBIMSO model, this module is elaborated into two sub-modules, *Planning* and *Control*. The process flowchart of *Maintenance Material Module* is presented in Figure 7-18.

As conducted on *Maintenance Tools Module*, the discussion on *Maintenance Material Planning Sub-Module* is also started from investigating whether the maintenance department has a classification of maintenance material/spare part to manage material stock. The classification of maintenance material is then accompanied by developing procedures to control such maintenance material/spare part. Furthermore, every maintenance treatment requires specific information of each spare part. Thus the KBIMSO model requests a detailed specification of each spare part in term of name, type, size, inventory code, etc. For performance assessment and evaluation, the KBIMSO facilitates *Material Control Sub-Module* which investigating current performance of maintenance function in managing its material through measuring error frequency on certain metrics.

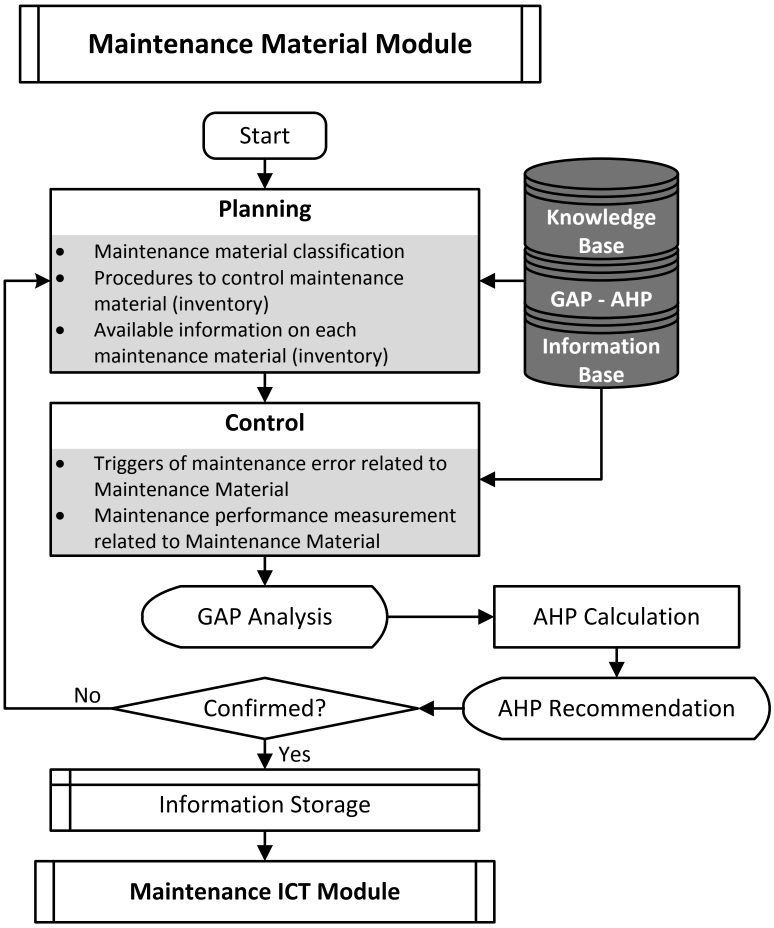


Figure 7-18 Flowchart of Level 5.3 – Maintenance Material Module

The example of generated KB rules of the *Maintenance Material Module* for *Maintenance Material Control Sub-Module* is illustrated as the following (only some KB rules presented):

IF *Outdated maintenance inventories (spare parts) cataloguing database is Low (< 25%): GP; Somewhat Low (25 - 40%): BP-PC-5, Moderate (40 - 60%): BP-PC-4, Somewhat High (60 - 80%): BP-PC-3, High (> 80%): BP-PC-2*

AND *Uncompleted inventory specification information is Low (< 25%): GP; Somewhat Low (25 - 40%): BP-PC-5, Moderate (40 - 60%): BP-PC-4, Somewhat High (60 - 80%): BP-PC-3, High (> 80%): BP-PC-2*

AND *Wrong inventory codes is Low (< 25%): GP; Somewhat Low (25 - 40%): BP-PC-5, Moderate (40 - 60%): BP-PC-4, Somewhat High (60 - 80%): BP-PC-3, High (> 80%): BP-PC-2*

AND *Wrong placement of inventories in the storeroom is Low (< 25%): GP; Somewhat Low (25 - 40%): BP-PC-5, Moderate (40 - 60%): BP-PC-4, Somewhat High (60 - 80%): BP-PC-3, High (> 80%): BP-PC-2*

AND	*Double storerooms for placing one type of inventory is Low (< 25%): GP; Somewhat Low (25 - 40%): BP-PC-5, Moderate (40 - 60%): BP-PC-4, Somewhat High (60 - 80%): BP-PC-3, High (> 80%): BP-PC-2*
AND	*Delay in repairing due to lack of spare part is Low (< 25%): GP; Somewhat Low (25 - 40%): BP-PC-5, Moderate (40 - 60%): BP-PC-4, Somewhat High (60 - 80%): BP-PC-3, High (> 80%): BP-PC-2*
THEN	*The company has a strong commitment to manage maintenance material*
OR	*The company has not strong commitment to manage maintenance material*

Since the KB rules highlight the frequency of error, Good Point (GP) is appointed to the lowest percentage of error. It means that the increase of the frequency of error causes the increase of maintenance material cost and the decrease of maintenance material efficiency. Considering the impact of each error on the overall maintenance performance, GAP analysis is ranging from PC-2 to PC-5.

7.4.4 Level 5.4 – Maintenance ICT Module

One of company competitiveness is an Information and Communication Technology (ICT) tool (Evans and Lindsay, 2010). Particularly for maintenance, many companies commonly use a kind of Computerised Maintenance Management System (CMMS) to manage their maintenance information system. It encompasses all information required to support maintenance function. This maintenance resource should be periodically reviewed and evaluated to ensure that all available information is accurate and useful to complete maintenance tasks. The KBIMSO model considers the importance of information and supporting tool to obtain, store and retrieve information. Different from *Maintenance Information and Documentation Module* in *Level 3 – Maintenance Rules* which discuss the company policy in managing information and documentation, this module focuses on ICT tool as a maintenance resource which supports maintenance activities. The process flowchart of *Maintenance ICT Module* is presented in Figure 7-19.

Maintenance ICT Planning Sub-Module is intended to check the integration of CMMS entities to support maintenance activities. When the required information is sent to CMMS, the system can provide maintenance tasks recommendation based on resources availability. Then, *Maintenance ICT Control Sub-Module* reviews any potential error and maintenance performance regarding CMMS implementation.

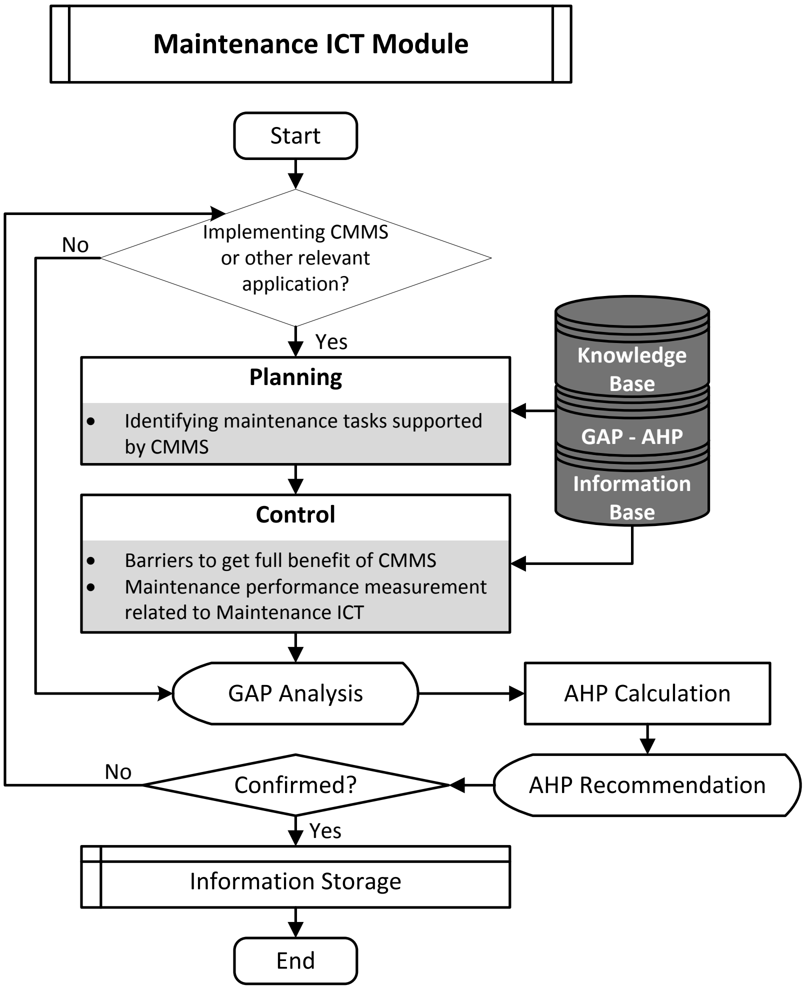


Figure 7-19 Flowchart of Level 5.4 – Maintenance ICT Module

The example of generated KB rules of the *Maintenance ICT Module* for *Maintenance ICT Planning Sub-Module* is illustrated as the following (only some KB rules presented):

IF *The company has Computerised Maintenance Management System (CMMS) or other relevant applications to support maintenance tasks (Yes: GP; No: BP-PC-2)*
AND *The company uses the CMMS for data collection (Yes: GP; No: BP-PC-3)*
AND *The company uses the CMMS for data processing (Yes: GP; No: BP-PC-3)*
AND *The company uses the CMMS for maintenance planning (Yes: GP; No: BP-PC-3)*
AND *The company uses the CMMS for maintenance scheduling (Yes: GP; No: BP-PC-3)*
AND *The company uses the CMMS for maintenance reporting (Yes: GP; No: BP-PC-3)*
AND *The company uses the CMMS for maintenance controlling (Yes: GP; No: BP-PC-3)*
THEN *The company has effectively used CMMS or other relevant applications to support maintenance tasks*

OR *The company has not effectively used CMMS or other relevant applications to support maintenance tasks*

OR *The company has no CMMS or other relevant applications to support maintenance tasks*

As can be seen on the set of KB rules above, the KBIMSO model is designed to know how deep the company involves CMMS within its maintenance function. When the maintenance department integrates its plan, schedule, and resources into CMMS, it could improve manufacturing performance and business competitiveness. Unless, the absence of such integration into a maintenance information system will cause inefficiency and impact on overall system performance, thus categorised as PC-3.

7.5 Chapter Summary

The discussion on this chapter is emphasised in the second stage of KBIMSO model, *Maintenance Operations Stage*. In the KBIMSO framework, this stage is categorised as *Conceptual Design Stage*, where this stage is dedicated to discuss maintenance system performance. As part of the KBIMSO model, *Maintenance Operations Stage* is subsequent the *Strategic Stage*, on which *Business* and *Manufacturing Perspective* are initially discussed regarding their interaction and contribution to maintenance.

There are three levels are discussed in *Maintenance Operations Stage*, which are *Level 3 – Maintenance Rules*, *Level 4 – Maintenance Activities*, and *Level 5 – Maintenance Resources*. *Level 3 – Maintenance Rules* consists of *Maintenance Policy Module*, *Maintenance Organisation Module*, and *Maintenance Information and Documentation Module*. *Level 4 – Maintenance Activities* consists of *Repairing Activity Module*, *Retaining Activity Module*, *Modification Activity Module*, and *Design Activity Module*. *Level 5 – Maintenance Resources* consists of *Maintenance Personnel Module*, *Maintenance Tools Module*, *Maintenance Material Module*, and *Maintenance ICT Module*. Each module is then explored in detail into two sub-modules to assist KPIs identification and classification process, which are *Planning* and *Control*.

Similar to the process on the first stage of KBIMSO model, the KB rules are generated on each module and sub-module in the form of IF… THEN… pattern. Each KB rule is attached to GAP analysis in term of Good Point and Bad Point.

While Good Point indicates the presence of KB rule statement in the company current situation, Bad Point indicates the absence of KB rule statement in the company current situation. Bad Point itself lies from the most important one to the less important one, so-called PC-1 to PC-9. Once the response of KBIMSO for *Maintenance Operations Stage* is fulfilled, AHP analysis is deployed to get the recommendation of improvement priority on all levels of KBIMSO to assist maintenance improvement plan. Next, Chapter 8 presents verification and validation process of KBIMSO to confirm that the KBIMSO works properly to provide consistent, valid, and rational recommendation for maintenance decision making.

CHAPTER 8

Verification and Validation of KBIMSO

8.1 Introduction

The thought that maintenance is an integral function of operations has been noticed since the middle of the twentieth century. Moreover, the companies adopted advanced technology and philosophy, such as Flexible Manufacturing System (FMS) and Just-In-Time (JIT). It confirms that maintenance contributes significantly to maintain satisfactory equipment and machine reliability (Haroun and Duffuaa, 2009). Therefore, to integrate maintenance with manufacturing and business goal, the KBIMSO model is developed. The KBIMSO model can map the current performance of maintenance and related aspects of manufacturing and business perspectives. The result will lead to the recommendation of improvement priority so the integrated maintenance strategy and operations can achieve a better performance to winning business competition.

The KBIMSO is intended to represent the real maintenance system, particularly on Body Part Manufacturing in the automotive company. One of the challenges in developing KBIMSO is to verify and validate the model thus it can work as expected and represent the real system to support decision making. Although they are commonly stated together, verification and validation have different purposes to test the KBIMSO model.

Verification is an internal analysis of the system related to procedure and calculation (Mosqueira-Rey et al., 2008). Verification of KBIMSO is intended to test the consistency and accuracy of KBIMSO application compared with the associated mathematical models (Hvala et al., 2005). There are two verifications conducted for KBIMSO, which are verification of calculation (GAP and AHP calculation) and verification of procedure (regarding KB rules and attached PC rating). Verification of calculation is conducted two times. First, when the KBIMSO has been developed, yet before validation process. Second, it is conducted simultaneously with the validation process. The KBIMSO is verified by examining the calculation of GAP and AHP on KBIMSO application towards manual calculation to ensure that the calculation of KBIMSO application produces a valid and consistent result. Meanwhile, verification of procedure is conducted once, only during the validation process. The users are requested to provide the feedback regarding the statements used on the KB rules and assigned PC rating, whether the KB rules are relevant to the subject discussed and appointed with suitable PC rating. The modification is then made when necessary.

Validation is used to ensure that the KBIMSO model works under the real system set up (Parida and Kumar, 2009) and can provide the benefit expected. In the validation process, the KBIMSO is generally treated as the “black box”, where the main concern of analysis is to ensure that the result achieved by the developed KBIMSO similar with expert’s recommendation (Mosqueira-Rey et al., 2008). The developed KBIMSO model is validated through two approaches, industrial case study and published case study. On industrial case study validation, all modules and sub-modules of KBIMSO are validated in two automotive companies. The company’s staff as the industrial practitioners are requested to be the users. The users fill in the response pages based on their best understanding, experience, and know-how. The responses are stored and then processed in the KBIMSO application to reach the result of recommendation. On the other hand, the published case study is addressed to validate *Financial Analysis Module* in *Level 1 – Business Perspective* which has quantitative information only. This module is validated by using released financial statements from a different company but on similar automotive industry background. The result of financial analysis calculated by the KBIMSO application is then compared with the financial analysis explained by the company in its annual report.

8.2 Automotive Companies Business Profile

Verification and validation of KBIMSO are conducted in two automotive companies in Indonesia. For some reasons, these companies do not want to be obviously stated in this thesis. Therefore, they are named as Company X and Y. Company X operates on producing, assembling, and selling motorcycles, while Company Y operates on producing, assembling, and selling four-wheel cars. The validation process in these companies was done separately in September – October 2016. The general descriptions of company profile are presented in the next section.

8.2.1 Business Profile of Company X

Company X, established in 1971, is a joint venture of two companies from Indonesia and Japan with an equal percentage of shares. It holds a licence for producing, assembling, distributing, and marketing some particular brands of motorcycles in Indonesia. Company X is supported by a Sales Operation Unit as one of the main dealers that take responsibility for selling the motorcycles, providing spare parts as well as supporting after-sale services.

As a large motorcycle industry, Company X has five plants (four of them are the assembly plants) in Jakarta with an installed production capacity of 5.8 million units per year. This company employs more than 22.000 employees and collaborates with more than 150 companies to supply its need to meet production target. It commits to implement latest production technology and distributes its products through a vast distribution network of dealers, outlets, auto workshops, and spare parts outlets. As the result, it secured more than half of national market share in 2015 with a sales volume of about 4.38 million units and starts to export its products to other countries.

The developed KBIMSO model was validated and verified particularly in the Body Part manufacturing station by a Production and Inventory Control (PIC) Manager who has more than 13 years working experience. He was assisted by some other staff from different departments to validate relevant aspects of KBIMSO model.

8.2.2 Business Profile of Company Y

Company Y, established in 1978, is an association entity among three companies from Indonesia and Japan. It holds a licence for producing, assembling, distributing, and marketing some particular brands of four-wheeler cars in Indonesia. It is supported by a Sales Operation Unit as the sole distributor that handle company’s sales and after-sales service network. Besides producing and selling products under its own brand, Company Y also has a responsibility to produce some products for other automotive companies under one parent company.

Company Y has four plants (two of them are the assembly plants) in Jakarta with an installed production capacity of 530,000 units per year. To support its production needs, this company collaborates with more than 150 suppliers and employs more than 10.700 employees. Besides producing cars for its own brands, Company Y also utilises its production facilities to produce some other brands for other companies. The latest plant is complemented by Research and Development Centre (RDC) which has a design studio to enable testing cars in more than 20 simulated extreme road conditions found all over the country. The RDC is improved continuously as part of Company Y commitment to ensure customer satisfaction on quality assurance. For this reason, Company Y is recorded as one of the top four-wheeler automotive companies by selling about 167.000 units and securing more than 16% of national market share in 2015. Both Company X and Y are noted as the top three subsidiaries to give the highest contribution of income to the parent company.

The developed KBIMSO model was validated and verified particularly in the Body Part manufacturing station by a Maintenance Manager who has more than 10 years working experience. He was assisted by some other staff from different departments to validate relevant aspects of KBIMSO model.

8.3 Verification and Validation of KBIMSO Based on the Industrial Data

Verification and validation are conducted simultaneously at all levels of KBIMSO. There are 6 levels altogether which consist of one preliminary level (Level 0), two strategic levels (Level 1 and 2) and three operational levels (Level 3, 4 and 5), which is reprinted below, by referring to Figure 5-20.

To get a fair comparison between two companies involved in the case study, the KBIMSO model is verified and validated on both Company X and Y in the same way. For the sake of brevity, only verification and validation process of Company X is detailed in this chapter. Meanwhile, for Company Y, only the summary of verification and validation is presented in this chapter to support the discussion and recommendation. The verification and validation process of Company Y is then presented in Appendix B.

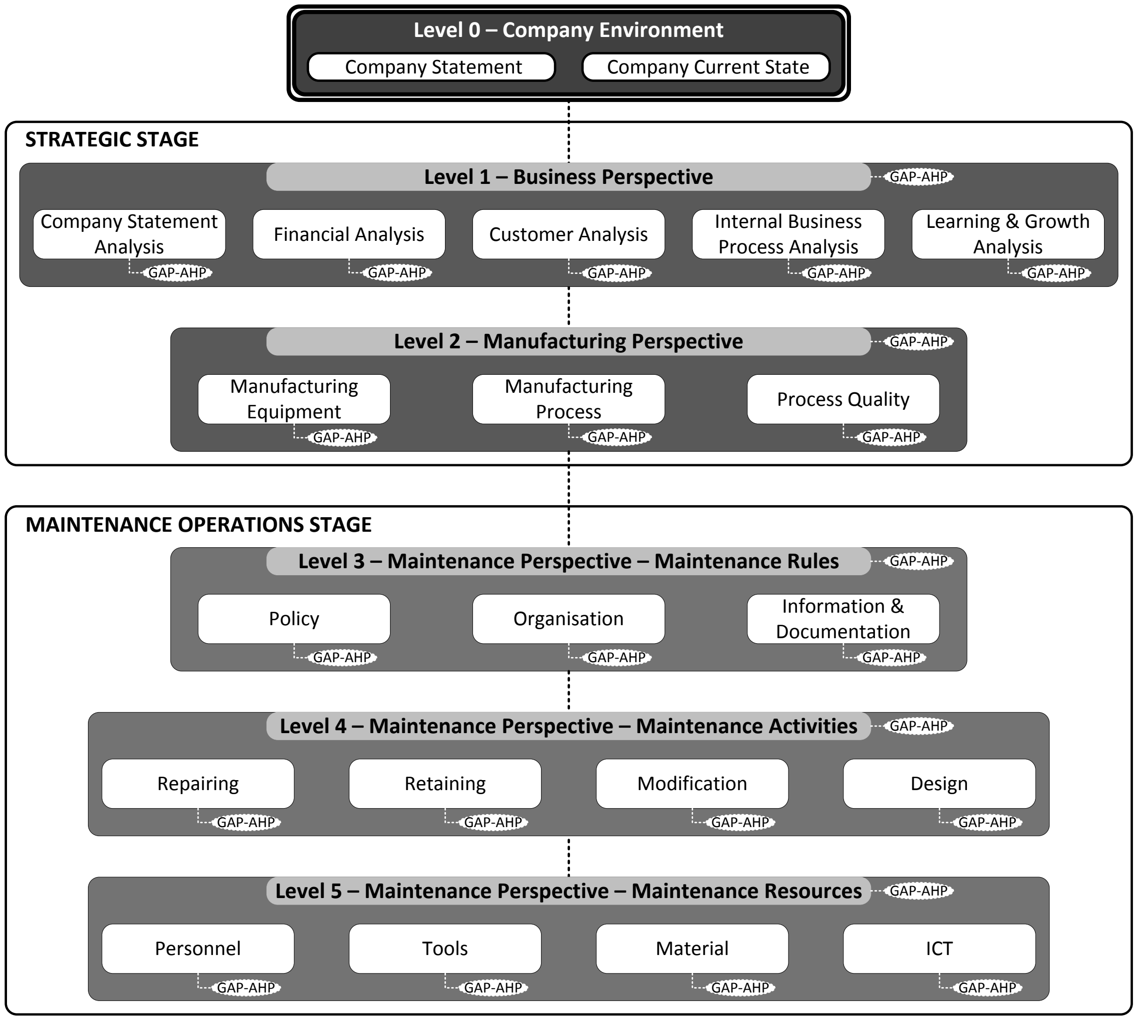


Figure 5-20 Structure of the KBIMSO model (Reprinted from Chapter 5)

8.3.1 Company X: Level 0 – Company Environment

Level 0 – Company Environment is addressed to show the general business profile of the company. There are two modules in *Level 0 – Company Environment*, which are *Company Statement Module* and *Company Current State Module*, as can be referred to Figure 6-3. To specify the use of that structure in Company X, the detailed structure of Level 0 is shown again in Figure 8-1. *Company Statement Module* requires the user to input the company statement; vision, mission, and objectives. Table 8-1 presents the availability of company statement of Company X.

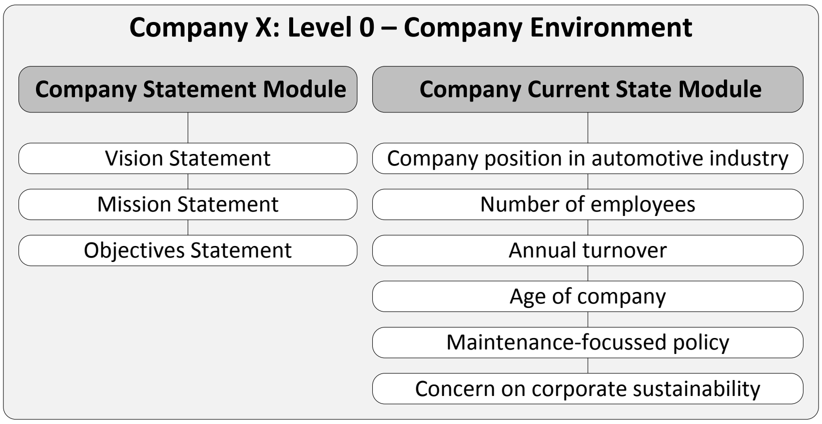


Figure 8-1 Company X: Detailed structure of Level 0 – Company Environment

Table 8-1 Availability of Company Statement of Company X

Company Statements	Avalailability
Vision Statement	Available
Mission Statement	Available
Objective Statement	Available

Company statement is very important as the formal direction of what future the company wants to be, what they are going to do to achieve it, and what the measurable and achievable steps required. Vision and mission will direct the leader to develop relevant strategies and objectives. It also can be used to lead the organisation to focus on the same objective, guide the teamwork, behaviour and corporate culture (Mullane, 2002). The statement of vision, mission, and objectives are not presented in this report to keep the company's privacy. In fact, those statements are available and shared internally as well as externally. However, the essence of this research is not stressed to criticise those statements, yet to ensure that the company has proper statements to guide the company's members in achieving company's goal.

The existing condition of the company is identified through the *Company Current State Module*. The KBIMSO application asks the user to fill in the information about user profile, company profile, business competitiveness, maintenance-focused activities, and corporate sustainability, where the result summarised in Table 8-2.

Table 8-2 Company Current State of Company X

User Profile	
Position	Production Planning and Inventory Control (PPIC) Manager
Management Level	Middle Level Management
Department	Manufacturing Department
Company Profile	
Position in Automotive Industry	Original Equipment Manufacturer (OEM)
Products	Motorcycles
Number of Employees	> 2500
Annual Turnover	> £ 50 million
Age of Organisation	45 years (established in 1971)
Business Competitiveness	
Number of Suppliers	> 150
Number of National Competitors	> 10
Market Place:	
National	Yes
Regional	Yes
Global	Not yet
Maintenance-focused Policy	
Corrective Maintenance	Yes
Preventive Maintenance	Yes
Predictive Maintenance	Yes
Aggressive Maintenance	Yes
Corporate Sustainability	
Social Programmes	Yes
Environmental Programmes	Yes

The information gathered from the *Company Current State Module* is mainly used to describe the company capability in the business environment and its concern on maintenance activities. By classifying the company size based on the number of employees and annual turnover, as can be referred to Table 5-2, it can be concluded that Company X is a large company.

Company age can also explain its maturity in the automotive industry. From the classification of the company based on age, as can be referred to Table 5-1, the company has reached the harvest level since the company can survive in the business for more than 45 years. The company's history explains that Company X dynamically transformed many times since 1971 to adjust to the changes in regulation, technology, and customer needs.

Considering the big marketplace in Indonesia, Company X mostly focuses on the national market. Some export activities have been started in some regional countries in Southeast Asia, but there is no record of the global market yet.

Furthermore, the discussion about market share is detailed with KB rules in *Level 1 – Business Perspective*, particularly in *Customer Analysis Module*.

The availability of maintenance policy in Company X indicates that the company has considered maintenance as the business driver and realised that maintenance should be carefully managed to win business competition. The implementation of maintenance-focused policy is furthermore represented by the synergy of maintenance rules, maintenance activities, and maintenance resources to ensure maintenance function can work properly to support manufacturing function. The discussion about maintenance is detailed with KB rules in *Maintenance Operations Stage* (Level 3, 4, and 5) of KBIMSO model.

Then, the commitment of Company X to get involved in social and environmental programmes gives the positive values to the society (Milana et al., 2014b). Not only supporting global sustainability, the company can align those issues with decision making on the operation and planning to improve business competitiveness (Ledoux et al., 2005). Furthermore, the discussion about social and environmental programmes is detailed with KB rules in *Level 1 – Business Perspective*, particularly in *Learning and Growth Analysis Module*.

The input obtained from Level 0 is then stored in the system to figure out the current state of Company X when KBIMSO model is applied. Since the aim of Level 0 is to give the preliminary information about Company X, there is no GAP and AHP analysis embedded with the KB rules in this level. The collaboration of KB system, GAP analysis and AHP analysis within the KBIMSO model is started from Level 1.

8.3.2 Company X: Level 1 – Business Perspective

Level 1 – Business Perspective is the first level in the *Strategic Stage* of KBIMSO model validated in Company X. It encompasses five modules, as can be referred to Figure 6-5. To specify the use of that structure in Company X, the detailed structure of Level 1 is shown again in Figure 8-2. Beside four perspectives of Balanced Scorecard (BSC), which are *Financial Analysis*, *Customer Analysis*, *Internal Business Process Analysis*, and *Learning and Growth Analysis*, the KBIMSO model for *Level 1 – Business Perspective* is complemented with another module, *Company Statement Analysis*, as the fundamental guidelines for the company to work together to achieve the goal. These five levels are then recognised to represent the business performance of Company X.

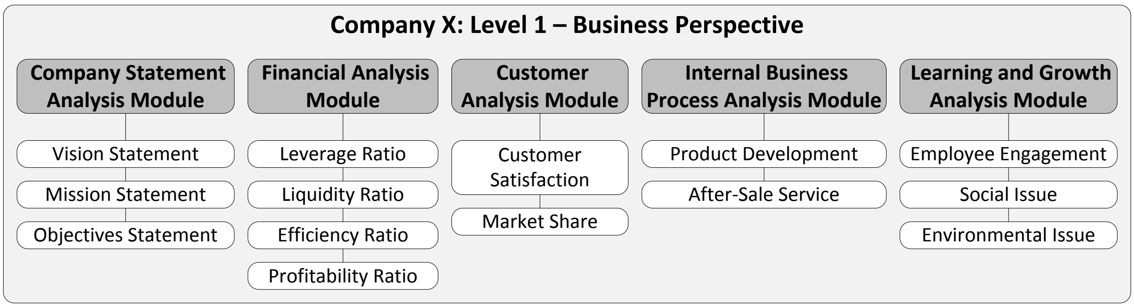


Figure 8-2 Company X: Detailed structure of Level 1 – Business Perspective

As explained in the previous chapters, GAP analysis is differentiated into two main categories, Good Point (GP) and Bad Point (BP). Particularly on BP, the bad point is scaled into nine Problem Categories (PCs), ranging from PC-1 to PC-9. PC-1 refers to the most crucial condition in the absence of KB rule, while PC-9 refers to the less important condition in the absence of KB rule. Having 383 KB rules in total, GAP analysis for Level 1 is tabulated in Table 8-3.

Table 8-3 Summary of GAP Analysis for Level 1 – Business Perspective of Company X

KBIMSO Level	Module	Sub-Module	Number of KB Rules	GAP Analysis for Company X										
				GP	BP	Problem Category (PC)								
						1	2	3	4	5	6	7	8	9
Level 1 Business Perspective	Company Statement Analysis	Value Socialisation	21	15	6	0	0	3	2	1	0	0	0	0
		Value Integration	14	11	3	0	3	0	0	0	0	0	0	0
		Sub-Total	**35**	**26**	**9**	**0**	**3**	**3**	**2**	**1**	**0**	**0**	**0**	**0**
	Financial Analysis	Leverage Ratio	15	10	5	0	1	4	0	0	0	0	0	0
		Liquidity Ratio	15	11	4	0	1	3	0	0	0	0	0	0
		Efficiency Ratio	6	2	4	0	3	1	0	0	0	0	0	0
		Profitability Ratio	16	10	6	0	4	2	0	0	0	0	0	0
		Sub-Total	**52**	**33**	**19**	**0**	**9**	**10**	**0**	**0**	**0**	**0**	**0**	**0**
	Customer Analysis	Customer Satisfaction	70	46	24	12	8	3	1	0	0	0	0	0
		Market Share	19	13	6	0	0	2	4	0	0	0	0	0
		Sub-Total	**89**	**59**	**30**	**12**	**8**	**5**	**5**	**0**	**0**	**0**	**0**	**0**
	Internal Business Process Analysis	Product Development	73	49	24	5	11	7	1	0	0	0	0	0
		After-sale Service	46	38	8	1	3	2	2	0	0	0	0	0
		Sub-Total	**119**	**87**	**32**	**6**	**14**	**9**	**3**	**0**	**0**	**0**	**0**	**0**
	Learning & Growth Analysis	Employee Engagement	69	53	16	2	6	2	4	1	1	0	0	0
		Social & Environmental Issue	19	14	5	0	0	0	0	4	0	1	0	0
		Sub-Total	**88**	**67**	**21**	**2**	**6**	**2**	**4**	**5**	**1**	**1**	**0**	**0**
	Total		**383**	**272**	**111**	**20**	**40**	**29**	**14**	**6**	**1**	**1**	**0**	**0**

The response given by the user from Company X shows there are 272 GPs out of 383 KB rules. The rest of 111 BPs is spread on seven PCs. By emphasising on the first four PCs as the higher important level to influence system performance, it is noted that there are 20 PC-1, 40 PC-2, 29 PC-3 and 14 PC-4 identified within Level 1, which spread among five modules. The majority of this BPs occurs in *Internal Business Process Analysis Module* (32 BPs). It is followed by *Customer Analysis Module* (30 BPs), *Learning and Growth Analysis Module* (21 BPs), *Financial Analysis Module* (19 BPs) and *Company Statement Analysis Module* (9 BPs). This indicates that there are some major aspects to be improved in disseminating and integrating the values of company statement to enhance company culture and staff behaviour on business level.

Following the GAP analysis, the KBIMSO model is continued with AHP analysis. In AHP, the sub-modules are compared through a pair-wise comparison to find priority of improvement should be taken under each module. Furthermore, after all sub-modules are examined, the pair-wise comparison is conducted among modules to determine the priority of improvement taken under each level.

8.3.2.1 Company X: Level 1.1 – Company Statement Analysis Module

In this module, there are 9 BPs are identified out of 35 KB rules, referring to Table 8-3. It means that there are 9 existing conditions in *Company Statement Analysis Module* that cannot meet the prerequisite conditions. These gaps (so-called BPs) are mostly found on the first four important PC scales, which are 3 PC-2, 3 PC-3, and 2 PC-4. A more investigation into KB rules on each sub-module reveals that there are 6 PCs identified in *Value Socialisation Sub-Module*, while there are 3 PCs identified in *Value Integration Sub-Module*. Furthermore, *Company Statement Analysis Module* is analysed with AHP method by conducting a pair-wise comparison between sub-modules to figure out the Priority Vector (PV), with the result shown in Table 8-4.

Table 8-4 AHP Analysis with PV for Company Statement Analysis Module of Company X

Com. Stat. Analysis Module	Value Socialisation	Value Integration	PV
Value Socialisation	1	1/2	0.3333
Value Integration	2	1	**0.6667**

From the above table, PV value of *Value Socialisation Sub-Module* is 0.3333 while PV value of *Value Integration Sub-Module* is 0.6667. This means that the aspects included in *Value Integration Sub-Module* get priority to be rectified rather than the aspects of *Value Socialisation Sub-Module*. By investigating the KB rules on this *Value Integration Sub-Module*, the crucial problem is caused by less attention of the company to put down the key stakeholders' needs within the company statement. Lack of clear statement about what company is going to do to meet the key stakeholders' needs will cut-down their support and loyalty. Later, when all five modules within Level 1 are compared, the priority of improvement will go to the module that has the highest PV value and will be concentrated to its sub-module which has the highest PV value.

8.3.2.2 Company X: Level 1.2 – Financial Analysis Module

Since the Company X is a private company which operates under the management of a parent company, the financial report of Company X is considered as confidential. Therefore, the user of KBIMSO from Company X cannot reveal the variables needed to complete KBIMSO model requirement on *Financial Analysis Module*. However, the parent company itself is a public company. It releases the annual report which contains the financial report. Although the financial data provided has been combined among some subsidiary companies, it is still relevant to count for KBIMSO model since the Company X is one of the large subsidiary companies that highly contributes to the parent company. Furthermore, strategic decisions made for all subsidiary companies are taken by Top Level Management in the parent company. The variables required for KBIMSO model on financial statements, which are *Income Statement* and *Balance Sheet*, are presented in Table 8-5 and Table 8-6.

Table 8-5 Income Statement (An exchange rate of £1.00 = Rp16,500.00)

INCOME STATEMENT			
Currency in Millions of Pound Sterling as of:	**Dec 31, 2015**	**Dec 31, 2014**	**Dec 31, 2013**
Net sales	11,163.39	12,224.30	11,750.30
Cost of goods sold	8,938.55	9,872.24	9,610.24
Other expenses	558.18	239.82	19.70
Depreciation	476.97	472.36	452.30
Earnings before interest and taxes (EBIT)	**1,189.70**	**1,639.88**	**1,668.06**
Net interest expense	69.64	178.18	174.55
Taxes	243.45	298.61	316.73
Net Income	**876.61**	**1,163.09**	**1,176.79**

Table 8-6 Balance Sheet (An exchange rate of £1.00 = Rp16,500.00)

BALANCE SHEET			
Currency in Millions of Pound Sterling as of:	**Dec 31, 2015**	**Dec 31, 2014**	**Dec 31, 2013**
ASSETS			
Current assets			
Cash & equivalents	1,642.55	1,266.79	1,124.67
Marketable securities	29.33	16.79	15.88
Receivables	3,212.42	3,318.73	3,130.00
Inventories	1,111.33	1,029.45	874.73
Other current assets	377.76	261.64	209.39
Total current assets	**6,373.39**	**5,893.39**	**5,354.67**
Net fixed assets (after depreciation)	2,527.39	2,500.00	2,294.67
Intangible assets	243.21	212.24	190.85
Other assets	5,730.85	5,699.03	5,129.15
TOTAL ASSETS	**14,874.85**	**14,304.67**	**12,969.33**
LIABILITIES & SHAREHOLDERS' EQUITY			
Current liabilities			
Debt due to repayment	725.76	641.58	779.03
Accounts payable	1,804.55	1,613.27	1,455.15
Other current liabilities	2,090.42	2,244.61	2,077.27
Total current liabilities	**4,620.73**	**4,499.45**	**4,311.45**
Long-term liabilities	2,585.45	2,521.15	2,222.24
Other long-term liabilities	-	-	-
TOTAL LIABILITIES	**7,206.18**	**7,020.61**	**6,533.70**
Total shareholders' equity	7,668.67	7,284.06	6,435.64
TOTAL LIABILITIES & SHAREHOLDERS' EQUITY	**14,874.85**	**14,304.67**	**12,969.33**

The information from the financial statements is used to calculate financial ratios. There are four ratios counted in the *Financial Analysis Module* of the KBIMSO model to determine the financial condition of the company, as the result presented in Table 8-7.

In this KBIMSO financial analysis, each ratio's value and its trend are attached to GAP analysis (in term of PC) to describe the impact of such financial condition on organisation performance. At the next step, AHP analysis is run to set the priority of improvement among those ratios, with the result presented in Table 8-8.

After conducting the pair-wise comparison among *Financial Analysis Modules*, the biggest PV value goes to *Efficiency Ratio* of 0.4841, which are followed by *Profitability Ratio* of 0.2311, *Leverage Ratio* of 0.1676, and *Liquidity Ratio* of 0.1171. The detailed analysis of KB rules and financial statements on *Efficiency Ratio* reveals that *Asset Turnover Ratio* last year and two years ago were less than 1. This means that the company cannot generate adequate sales compared to its asset. In addition, the values of three-year data show negative trends which are critical and categorised as PC-2.

Table 8-7 KBIMSO Financial Analysis

FINANCIAL ANALYSIS						
As of:	**Dec 31, 2015**		**Dec 31, 2014**		**Dec 31, 2013**	
Financial Ratio	**Value**	**(Category)**	**Value**	**(Category)**	**Value**	**(Category)**
Leverage Ratio						
Debt Ratio (DR)	0.48	(GP)	0.49	(GP)	0.50	(PC-3)
DR Trend (Category)	decreased (GP)		decreased (GP)			
Debt Equity Ratio (DER)	0.94	(PC-2)	0.96	(PC-3)	1.02	(PC-3)
DER Trend (Category)	decreased (GP)		decreased (GP)			
Times Interest Earned Ratio (TIER)	17.08	(GP)	9.20	(GP)	9.56	(GP)
TIER Trend (Category)	increased (GP)		decreased (PC-3)			
Liquidity Ratio						
Current Ratio (CurR)	1.38	(GP)	1.31	(GP)	1.24	(GP)
CurR Trend (Category)	increased (GP)		increased (GP)			
Cash Ratio (CasR)	0.36	(PC-2)	0.29	(PC-3)	0.26	(PC-3)
CasR Trend (Category)	increased (GP)		increased (GP)			
Quick Ratio (QR)	1.06	(GP)	1.02	(GP)	0.99	(PC-3)
QR Trend (Category)	increased (GP)		increased (GP)			
Efficiency Ratio						
Asset Turnover Ratio (ATR)	0.77	(PC-2)	0.90	(PC-3)		
ATR Trend (Category)	decreased (PC-2)					
Inventory Turnover Ratio (ITR)	8.35	(GP)	10.37	(GP)		
ITR Trend (Category)	decreased (PC-2)					
Profitability Ratio						
Net Profit Margin Ratio (NPMR)	0.08	(GP)	0.10	(GP)	0.10	(GP)
NPMR Trend (Category)	decreased (PC-2)		decreased (PC-3)			
Return on Assets Ratio (RoA)	0.06	(GP)	0.10	(GP)		
RoA Trend (Category)	decreased (PC-2)					
Return on Equity Ratio (RoE)	0.12	(GP)	0.17	(GP)		
RoE Trend (Category)	decreased (PC-2)					
Return on Investment Ratio (RoI)	0.06	(GP)	0.08	(GP)	0.09	(GP)
RoI Trend (Category)	decreased (PC-2)		decreased (PC-3)			

Table 8-8 AHP Analysis with PV for Financial Analysis Module

Financial Analysis Module	Leverage Ratio	Liquidity Ratio	Efficiency Ratio	Profitability Ratio	PV
Leverage Ratio	1	2	1/3	1/2	0.1676
Liquidity Ratio	1/2	1	1/3	1/2	0.1171
Efficiency Ratio	3	3	1	3	**0.4841**
Profitability Ratio	2	2	1/3	1	0.2311

8.3.2.3 Company X: Level 1.3 – Customer Analysis Module

By referring to Table 8-3, it is noticed that the gap on *Customer Analysis Module* is dominated by *Customer Satisfaction Sub-Module* by having 12 PC-1, 8 PC-2, 3 PC-3, and 1 PC-4. Meanwhile, *Market Share Sub-Module* has a fewer BPs, which are 2 PC-3 and 4 PC-4. Clearly, from GAP analysis, *Customer Satisfaction Sub-Module* is more problematic than *Market Share Sub-Module*. To confirm this indication, the priority of improvement under this module is weighted through AHP analysis, as shown in Table 8-9.

Table 8-9 AHP Analysis with PV for Customer Analysis Module of Company X

Customer Analysis Module	Customer Satisfaction	Market Share	PV
Customer Satisfaction	1	3	**0.7500**
Market Share	1/3	1	0.2500

PV value of *Customer Satisfaction Sub-Module* is higher than PV value of *Market Share Sub-Module*, which are 0.7500 and 0.2500, respectively. It consistently indicates that *Customer Satisfaction Sub-Module* requires priority for evaluation and rectification within this module. A further investigation on KB rules finds that there are some aspects of customer satisfaction factor, both tangible and intangible aspects, need more attention to increase customer satisfaction level.

8.3.2.4 Company X: Level 1.4 – Internal Business Process Analysis Module

All BPs identified in *Internal Business Process Analysis Module* are concentrated on first four PCs, which mean that those problems are crucial to influence system performance. From 32 BPs identified on this module, there are 24 BPs found in *Product Development Sub-Module* (5 PC-1, 11 PC-2, 7 PC-3, and 1 PC-4), and 8 BPs found in *After-Sale Service Sub-Module* (1 PC-1, 3 PC-2, 2 PC-3, and 2 PC-4). To set the improvement priority, the AHP analysis with a pair-wise comparison is conducted, where the result shown in Table 8-10.

Table 8-10 AHP Analysis with PV for Internal Business Process Analysis Module of Company X

Internal Business Process Module	Product Development	After-sale Service	PV
Product Development	1	2	**0.6667**
After-sale Service	1/2	1	0.3333

When these sub-modules are analysed through AHP method, PV value of *Product Development Sub-Module* is 0.6667, higher than PV value of *After-sale Service Sub-Module,* which is 0.3333. By this, the priority of improvement under this module is focused on *Product Development Sub-Module*. The gaps on this sub-module spread on commitment, market research and product innovation aspects.

8.3.2.5 Company X: Level 1.5 – Learning and Growth Analysis Module

Learning and Growth Analysis Module consists of 88 KB rules. The response of KBIMSO from Company X shows that *Employee Engagement Sub-Module* has 16 BPs out of 59 KB rules and *Social and Environment Issue Sub-Module* has 5 BPs out of 19 KB rules. There are some important problems identified on *Employee Engagement Sub-Module*, where the BPs lie from PC-1 to PC-6, but 14 BPs of them are concentrated on the first four PCs (2 PC-1, 6 PC-2, 2 PC-3, and 4 PC-4). Meanwhile, all BPs found on *Social and Environmental Issue Sub-Module* are concentrated on less important BPs (PC-5 to C-9), which are 4 PC-5 and 1 PC-7. However, the BPs lie on PC-5 to PC-9 might still be counted when its total weight significantly influences PV value. The result of AHP analysis on *Learning & Growth Analysis Modules* presented in Table 8-11.

Table 8-11 AHP Analysis with PV for Learning & Growth Analysis Module of Company X

Learning & Growth Analysis Module	Product Development	After-sale Service	PV
Employee Engagement	1	2	**0.6667**
Social & Environmental Issue	1/2	1	0.3333

Through AHP analysis, the PV value is determined to set improvement priority. The result of AHP analysis in Table 8-11 shows that PV value of *Employee Engagement Sub-Module* is 0.6667 while PV value of *Social and Environmental Issue Sub-Module* is 0.3333. Therefore, the improvement in *Learning and Growth Analysis Module* is prioritised on *Employee Engagement* aspects, which is related to management commitment, career information and regulation, skill improvement, and corporate culture.

8.3.2.6 Company X: Summary of Level 1 – Business Perspective

By completing the AHP analysis of *Learning and Growth Analysis Module* for Company X, the KBIMSO process of each module on *Level 1 – Business Perspective* has been accomplished; refer to the flowchart of each module, from Figure 6-10 to Figure 6-14. By this, recommended sub-module to be rectified on each module has also been proposed. Next, at the end of validation for Level 1, the pair-wise comparison is examined across modules to figure out the most problematic area in *Level 1* based on AHP analysis, refer to the flowchart in Figure 6-6. The result of AHP analysis is presented in Table 8-12 while the summary of AHP analysis for *Level 1 – Business Perspective Module* is presented in Table 8-13.

Table 8-12 AHP Analysis with PV for Level 1 – Business Perspective of Company X

Business Perspective Level	Comp. Stat. Analysis	Financial Analysis	Customer Analysis	Int. Bus. Proc. Analysis	L & G Analysis	PV
Comp. Stat. Analysis	1	1/2	1/3	1/2	2	0.1274
Financial Analysis	2	1	1/2	2	2	0.2357
Customer Analysis	3	2	1	2	3	**0.3611**
Int. Bus. Proc.	2	1/2	1/2	1	2	0.1801
L & G Analysis	1/2	1/2	1/3	1/2	1	0.0957

Table 8-13 Summary of AHP Analysis with PV for Level 1 – Business Perspective of Company X

KBIMSO Level	**Module**	**PV**	**Sub-Module**	**PV**
Level 1 Business Perspective	Company Statement Analysis	0.1274	Value Socialisation	0.3333
			Value Integration	**0.6667**
	Financial Analysis	0.2357	Leverage Ratio	0.1676
			Liquidity Ratio	0.1171
			Efficiency Ratio	**0.4841**
			Profitability Ratio	0.2311
	Customer Analysis	**0.3611**	**Customer Satisfaction**	**0.7500**
			Market Share	0.2500
	Internal Business Process Analysis	0.1801	**Product Development**	**0.6667**
			After-sale Service	0.3333
	Learning & Growth Analysis	0.0957	**Employee Engagement**	**0.6667**
			Social & Environmental Issue	0.3333

When the modules on *Level 1* are compared through pair-wise comparison, the PV can notice which module that requires improvement more than others in order to increase system performance of Company X regarding maintenance. The highest PV is identified on *Customer Analysis* which has PV value of 0.3395. It is followed by *Internal Business Process*, *Financial Analysis*, *Learning and Growth Analysis*, and *Company Statement Analysis*, with PV value of 0.2397, 0.1842, 0.1408, and 0.0958, respectively. Since *Customer Analysis Module* is recommended to get the first improvement than others, the improvement plan is derived from the most problematic sub-module in such module, as referred to Table 8-13.

As the AHP analysis has been conducted to this module, it can be found on the summary that the priority sub-module in *Customer Analysis Module* is *Customer Satisfaction Sub-Module*. The crucial aspects to improve on this sub-module can be retrieved from the database of KBIMSO Company X on information storage. The detailed recommendation for this level is compiled with other levels and discussed later in the Summary of Verification and Validation of the KBIMSO Model for Company X, in Section 8.4.1.

8.3.3 Company X: Level 2 – Manufacturing Perspective

This section discusses the verification and validation process on Company X for *Level 2* of KBIMSO. *Level 2 – Manufacturing Perspective* is another subject in *Strategic Stage* that influences maintenance performance. It consists of three modules, as can be referred to Figure 6-15. To specify the use of that structure in Company X, the detailed structure of Level 2 is shown again in Figure 8-3, which are *Manufacturing Equipment Module*, *Manufacturing Process Module,* and *Process Quality Module*. These aspects are noticed to mostly relate to maintenance function. The interaction between manufacturing and maintenance are developed by ensuring that maintenance function can support manufacturing function to get expected equipment performance to execute expected manufacturing process in order to produce expected quality of the product.

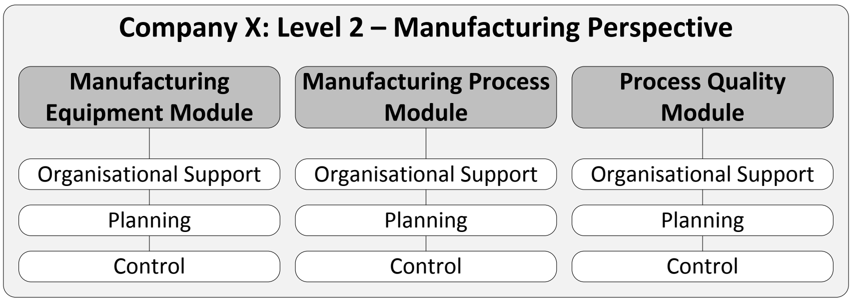


Figure 8-3 Company X: Detailed structure of Level 2 – Manufacturing Perspective

On this level, each module is assessed through the similar aspect of sub-modules. This is intended to articulate and examine the manufacturing modules through similar subjects. Nonetheless, the material discussed on each module refers to its own requirement. First, *Organisational Support Sub-Module* is addressed to figure out management commitment from Top Level to Lower Level Management. Second, *Planning Sub-Module* is focused to identify requirement towards the benchmarks. Third, *Control Sub-Module* is intended to evaluate existing condition and achievements of certain programmes.

Following the similar pattern of GAP analysis in the previous level, this level also has KB rules that are embedded with GP and BP (where BP is represented through PC-1 to PC-9). Each KB rule has different PC regarding the importance and impact of such rule to system performance. Having 288 KB rules in total, the result of GAP analysis for *Level 2* of KBIMSO in Company X is tabulated in Table 8-14.

Table 8-14 Summary of GAP Analysis for Level 2 – Manufacturing Perspective of Company X

KBIMSO Level	Module	Sub-Module	Number of KB Rules	GAP Analysis for Company X										
				GP	BP	Problem Category (PC)								
						1	2	3	4	5	6	7	8	9
Level 2 Manufacturing Perspective	Manufacturing Equipment	Organisational Support	47	28	19	8	2	8	1	0	0	0	0	0
		Planning	10	6	4	1	0	1	0	1	1	0	0	0
		Control	26	11	15	0	1	1	6	7	0	0	0	0
		Sub-Total	**83**	**45**	**38**	**9**	**3**	**10**	**7**	**8**	**1**	**0**	**0**	**0**
	Manufacturing Process	Organisational Support	48	36	12	3	2	5	0	0	1	1	0	0
		Planning	49	40	9	2	3	1	1	0	0	0	2	0
		Control	27	14	13	0	0	1	3	9	0	0	0	0
		Sub-Total	**124**	**90**	**34**	**5**	**5**	**7**	**4**	**9**	**1**	**1**	**2**	**0**
	Process Quality	Organisational Support	48	31	17	8	1	6	1	1	0	0	0	0
		Planning	21	15	6	0	2	0	0	3	1	0	0	0
		Control	12	6	6	0	0	1	1	4	0	0	0	0
		Sub-Total	**81**	**52**	**29**	**8**	**3**	**7**	**2**	**8**	**1**	**0**	**0**	**0**
	Total		**288**	**187**	**101**	**22**	**11**	**24**	**13**	**25**	**3**	**1**	**2**	**0**

Out of a total of 288 KB rules, there are 185 GPs and 101 BPs. BPs are further classified into PCs as follows: 22 PC-1, 11 PC-2, 24 PC-3, 13 PC-4, 25 PC-5, 3 PC-6, 1 PC-7, and 2 PC-8. *Manufacturing Equipment Module* is noted to have the biggest problem with 38 BPs, which is followed by *Manufacturing Process Module* with 34 BPs, and *Process Quality Module* with 29 BPs. By weighting each PC of GAP analysis and assigned it to the Intensity of Importance of AHP analysis, the priority of improvement can be set based on the PV values. The following sections discuss the priority of improvement among sub-modules under each module in Level 2. At last, the priority of improvement across modules under Level 2 is determined.

8.3.3.1 Company X: Level 2.1 – Manufacturing Equipment Module

From a total of 83 KB rules in *Manufacturing Equipment (ME) Module* of Company X, referring to Table 8-14, there are 38 BPs found which are mostly situated on the first four of PCs (9 PC-1, 3 PC-2, 10 PC-3, 7 PC-4, 8 PC-5, and 1 PC-6). The gaps on this module mostly arise on *ME Organisation Support Sub-Module* which has 19 BPs, and all of them are categorised as important and cause a crucial problem (on the range of PC-1 to PC-4). Meanwhile, *ME Control Sub-Module* follows by having 15 BPs, but only half of this BPs is counted as major problems. Eventually, *ME Planning Sub-Module* has a small number of BPs by having 1 PC-1, 1 PC-3, 1 PC-5 and 1 PC-6. The AHP analysis for Level 2.1 produces the recommendation by determining PV value of each sub-module, where the result presented in Table 8-15.

Table 8-15 AHP Analysis with PV for Manufacturing Equipment Module of Company X

Mfg. Equipment Module	Org. Support	Planning	Control	PV
Org. Support	1	2	2	**0.4905**
Planning	0.5	1	2	0.3119
Control	1/2	1/2	1	0.1976

The table above shows PV values for *ME Organisational Support*, *ME Planning*, and *ME Control* sub-modules on *Manufacturing Equipment Module*. PV value for *ME Organisational Support* is 0.4905, *ME Planning* is 0.3119, and *ME Control* is 0.1976. Therefore, the priority for Company X to focus on this *Manufacturing Equipment Module* is to improve *ME Organisational Support Sub-Module*, before taking any action on *ME Planning Sub-Module* (second priority) or *ME Control Sub-Module* (last priority). From the KB rules database, a number of problems are found on management commitment and multi-department collaboration to support manufacturing equipment performance.

8.3.3.2 Company X: Level 2.2 – Manufacturing Process Module

Referring to Table 8-14, out of 124 KB rules, *Manufacturing Process (MP) Module* of Company X contains 90 GPs and 34 BPs. Although *MP Control Sub-Module* has the biggest number of BPS, which is 13 BPs, only 4 of them are categorised as critical to the system performance (1 PC-3 and 3 PC-4). On *MP Organisational Support Sub-Module*, which has 12 BPs, 10 of them are classified as critical problems by having 3 PC-1, 2 PC-2, and 5 PC-3. The rest of BPs is identified on *MP Planning Sub-Module* which has 2 PC-1, 3 PC-2, 1 PC-3, 1 PC-4, and 2 PC-5. Through GAP analysis it can be noticed which sub-module that has more BPs than other. However, AHP analysis is required to weight them to find out which sub-module should get the priority of improvement, with the result shown in Table 8-16.

Table 8-16 AHP Analysis with PV for Manufacturing Process Module of Company X

Mfg. Process Module	Org. Support	Planning	Control	PV
Org. Support	1	2	2	**0.4905**
Planning	1/2	1	1/2	0.1976
Control	1/2	2	1	0.3119

Different from other modules, *Manufacturing Process Module* has a different result of GAP analysis and AHP analysis. In spite of *MP Control Sub-Module* has the most BPs, the highest PV value is appointed to *MP Organisational Support Sub-Module* since the weight of PCs on this sub-module is higher that *MP Control Sub-Module*. PV value of *MP Organisational Support Sub-Module* is 0.4905, while PV value of *MP Control Sub-Module* is 0.3119 and *MP Planning Sub-Module* is 0.1976. By this, the priority of improvement under *Manufacturing Process Module* is addressed to *MP Organisational Support Sub-Module*. From the KB rules, it can be identified that the majority problems are related to management commitment in setting the performance target and reviewing the plans/programmes.

8.3.3.3 Company X: Level 2.3 – Process Quality Module

Referring again to Table 8-14, *Process Quality (PQ) Module* is built from 81 KB rules. Settle down with 52 GPs, Company X still missed 29 KB rules toward the prerequisite circumstances, which classified as BPs. The majority of BPs lies on critical issues by having 8 PC-1, 3 PC-2, 7 PC-3, and 2 PC-4 on the first four of PCs. The further analysis on each sub-module highlights *PQ Organisational Support Sub-Module* that has more problems than other sub-module by containing 17 BPs (8 PC-1, 1 PC-2, 6 PC-3, 1 PC-4, and 1 PC-5). Meanwhile, the other two sub-modules, *PQ Planning Sub-Module* and *PQ Control Sub-Module*, similarly have 6 BPs spread at a different level of PC. To confirm the priority of improvement on sub-module under this *Process Quality Module*, AHP analysis is conducted to find out the highest PV values among the sub-modules. The result of AHP analysis is presented in Table 8-17.

Table 8-17 AHP Analysis with PV for Process Quality Module of Company X

Process Quality Module	Org. Support	Planning	Control	PV
Org. Support	1	3	3	**0.5889**
Planning	1/3	1	1/2	0.1593
Control	1/3	2	1	0.2519

PV values on *PQ Organisational Support*, *PQ Planning*, and *PQ Control* sub-modules are 0.5589, 0.1593, and 0.2519, respectively. Considering the highest PV value, the priority of improvement is recommended on *PQ Organisation Support Sub-Module* before improving the other two sub-modules. The problematic KB rules mostly relate to management culture, span of authority, and interaction among management levels.

8.3.3.4 Company X: Summary of Level 2 – Manufacturing Perspective

After the discussion about each module within *Level 2 – Manufacturing Perspective*, the KBIMSO model is continued by comparing modules through pair-wise comparison of AHP analysis to obtain the recommendation for Level 2, as mentioned on the flowchart, referring back to Figure 6-16. With the similar procedures as of finding PV values, the result of AHP analysis for *Level 2* is presented in Table 8-18, while the summary of AHP analysis for *Level 2 – Manufacturing Perspective* is presented in Table 8-19.

Table 8-18 AHP Analysis with PV for Level 2 – Manufacturing Perspective of Company X

Mfg. Perspective Level	Mfg. Equipment	Mfg. Process	Process Quality	PV
Mfg. Equipment	1	2	2	**0.4905**
Mfg. Process	1/2	1	1/2	0.1976
Process Quality	1/2	2	1	0.3119

Table 8-19 Summary of AHP Analysis with PV for Level 2 – Manufacturing Perspective of Company X

KBIMSO Level	Module	PV	Sub-Module	PV
Level 2 Manufacturing Perspective	**Manufacturing Equipment**	**0.4905**	**Organisational Support**	**0.4905**
			Planning	0.3119
			Control	0.1976
	Manufacturing Process	0.1976	**Organisational Support**	**0.4905**
			Planning	0.1976
			Control	0.3119
	Process Quality	0.3119	**Organisational Support**	**0.5889**
			Planning	0.1593
			Control	0.2519

From Table 8-18, the highest PV value is 0.4905 which is addressed to *Manufacturing Equipment Module*. It is followed by *Process Quality Module* and *Manufacturing Process Module* with PV values of 0.3119 and 0.1976, respectively. Therefore, the first improvement plan is prioritised to increase manufacturing equipment performance. To reach deeply into that selected module, the AHP analysis on each module is retrieved, as summarised in Table 8-19. The selected sub-module that requires initial improvement within *Manufacturing Equipment Module* is *ME Organisation Support Sub-Module*, which has the highest PV value under that module. The detailed recommendation for this level is compiled with other levels and discussed later in the Summary of Verification and Validation of the KBIMSO Model for Company X, in Section 8.4.1.

8.3.4 Company X: Level 3 – Maintenance Rules

Level 3 – Maintenance Rules is the third level in KBIMSO model, but the first level in *Maintenance Operations Stage*. This level consists of three modules: *Maintenance Policy Module*, *Maintenance Organisation Module*, and *Maintenance Information and Documentation Module*. The detailed structure of

KBIMSO for Company X on *Level 3 – Maintenance Rules* as can be referred to Figure 7-3. To specify the use of that structure in Company X, the detailed structure of Level 3 is presented again in Figure 8-4.

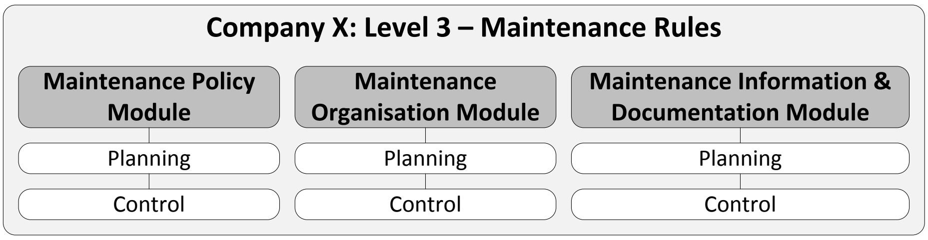


Figure 8-4 Company X: Detailed structure of Level 3 – Maintenance Rules

Maintenance function requires particular rules to ensure maintenance programmes can support manufacturing function as well as drive business competitiveness effectively and efficiently. *Maintenance Policy Module* concerns on organisational support, such as commitment of all management levels and functions collaboration of Company X to support maintenance programmes. *Maintenance Organisation Module* responds to the dynamic changes in maintenance which will influence the way of coordination among maintenance entities. *Maintenance Information and Documentation Module* works to check the integrity of maintenance function in documenting all available information and provide it to serve maintenance tasks.

Different from modules on *Manufacturing Perspective Level* which contain three sub-modules; *Organisational Support*, *Planning*, and *Control*, each module on *Maintenance Perspective Levels* consists of two sub-modules; *Planning* and *Control*. To get the detail aspects of maintenance as the main subject of this research, the critical points of organisational support are highlighted in a particular module called *Maintenance Policy*. Furthermore, the summary of KBIMSO response on this level for Company X is presented in Table 8-20.

Table 8-20 Summary of GAP Analysis for Level 3 – Maintenance Rules of Company X

KBIMSO Level	Module	Sub-Module	Number of KB Rules	GAP Analysis for Company X										
				GP	BP	Problem Category (PC)								
						1	2	3	4	5	6	7	8	9
Level 3 Maintenance Perspective - Maintenance Rules	Maintenance Policy	Planning	52	33	19	5	3	8	1	0	1	1	0	0
		Control	29	23	6	0	0	1	2	2	0	0	1	0
		Sub-Total	**81**	**56**	**25**	**5**	**3**	**9**	**3**	**2**	**1**	**1**	**1**	**0**
	Maintenance Organisation	Planning	17	11	6	0	0	2	1	1	0	1	0	1
		Control	11	1	10	0	0	1	3	6	0	0	0	0
		Sub-Total	**28**	**12**	**16**	**0**	**0**	**3**	**4**	**7**	**0**	**1**	**0**	**1**
	Maintenance Inf. & Doc.	Planning	20	13	7	3	4	0	0	0	0	0	0	0
		Control	7	1	6	0	0	1	2	3	0	0	0	0
		Sub-Total	**27**	**14**	**13**	**3**	**4**	**1**	**2**	**3**	**0**	**0**	**0**	**0**
	Total		**136**	**82**	**54**	**8**	**7**	**13**	**9**	**12**	**1**	**2**	**1**	**1**

A total of 136 KB rules has been designed and developed for this particular level. Referring to the result shown in the above table, out of 136 KB rules, there are 82 GPs and 54 BPs. The GP means that the company has achieved the benchmark. This GP is defined as a single parameter without any classification. Differently, BP means that the company practice has not reached the prerequisites condition as expected on the benchmark. Since the importance of KB rules is different based on its criticality to the system performance, the BP (the absence of KB rule) is assigned to different PC level. The BPs on this level are further classified into PCs as follows; 8 PC-1, 7 PC-2, 13 PC-3, 9 PC-4, 12 PC-5, 1 PC-6, 2 PC-7, 1 PC-8, and 1 PC-9. The majority of KB rules is developed for *Maintenance Policy Module* to figure out the roles of each management level to assist maintenance programmes and confirm the commitment of Company X to support maintenance function. By considering the number of KB rules developed on each module against the BPs found, it can be seen that the proportion of BPs on each module is around a half of total KB rules, more or less. Therefore, it is important to weight that BPs proportionally thus the biggest problem can be found and tackled based on priority. For this reason, AHP analysis with its 'pair-wise comparison' and 'weight for priority' is deployed to sort the PV values of sub-modules and modules under this level.

8.3.4.1 Company X: Level 3.1 – Maintenance Policy Module

Out of a total 81 KB rules generated in *Maintenance Policy (MPol) Module*, referring to Table 8-20, there are 56 GPs and 25 BPs identified. *MPol Planning Sub-Module* contains 25 BPs which represent 25 gaps between current and prerequisite conditions. These BPs majority spread on the first four PCs, which indicate the important problems; 5 PC-1, 3 PC-2, 9 PC-3, and 3 PC-4. Meanwhile, only 5 BPs are categorised as the less important problem (PC-5 to PC-9). Differently, *MPol Control Sub-Module* only has 6 BPs out of 29 KB rules developed. Half of BPs is found in the important range of PCs (PC-1 to PC-4) whilst another half is found in the less important range of PCs (PC-5 to PC-9). To confirm the priority of improvement that should be taken, AHP analysis is conducted where the result presented in Table 8-21.

Table 8-21 AHP Analysis with PV for Maintenance Policy Module of Company X

Maintenance Policy Module	Planning	Control	PV
Planning	1	3	**0.7500**
Control	1/3	1	0.2500

PV values can represent the weight of importance of a sub-module against another. PV value of *MPol Planning Sub-Module* is 0.7500 while PV value of *MPol Control Sub-Module* is 0.2500. It apparently confirms that *MPol Planning Sub-Module* requires improvement more than *MPol Control Sub-Module*. The critical gaps in *MPol Planning Sub-Module* are concentrated on some corporate cultures of management levels in supporting maintenance performance to reach benchmarks.

8.3.4.2 Company X: Level 3.2 – Maintenance Organisation Module

Maintenance Organisation (MOrg) Module is examined through 28 KB rules. Referring to Table 8-20, the response from the user of Company X showed that 12 KB rules are defined as GPs, while 16 KB rules are defined as BPs. *MOrg Planning Sub-Module* has collected 11 GPs and 6 BPs while *MOrg Control Sub-Module* has collected 1 GP and 10 BPs. However, there is no BP found on the first two PCs. The majority of BPs on both sub-modules is located on PC-3, PC-4, and PC-5. To get a right comparison between them, the pair-wise comparison is attempted to determine the PV of each sub-module through AHP analysis. The result of PV is presented in Table 8-22.

Table 8-22 AHP Analysis with PV for Maintenance Organisation Module of Company X

Maintenance Organisation Module	Planning	Control	PV
Planning	1	1/3	0.2500
Control	3	1	**0.7500**

AHP analysis weights each PC based on its importance then compares the sub-modules to decide which one has the higher PV than another. From the table above, *MOrg Control Sub-Module* has PV of 0.7500, higher than *MOrg Planning Sub-Module* which has PV of 0.2500. This means that *Maintenance Organisation Module* has to set priority on *Control* aspects to improve before rectifying *Planning* aspects. Based on the identified BPs on *MOrg Control Sub-Module*, the improvement is required on all aspects related to maintenance organisation in order to increase the effectiveness and efficiency of maintenance performance.

8.3.4.3 Company X: Level 3.3 – Maintenance Information & Documentation Module

The last module developed in Maintenance Rules is *Maintenance Information and Documentation (MID) Module*. The response collected from Company X reveals that from a total of 27 KB rules, there are 14 GPs and 13 BPs identified in this module, referring to Table 8-20. *MID Planning Sub-Module* has 7 BPs which are concentrated on two most critical PCs (3 PC-1 and 4 PC-2). Meanwhile, *MID Control Sub-Module* has 6 BPs which are classified into 1 PC-3, 2 PC-4, and 3 PC-5. By weighting the identified PCs, the result of GAP analysis is used to set the priority of improvement through PV values of AHP analysis. The PV values for sub-modules on *Maintenance Information & Documentation Module* are shown in Table 8-23.

Table 8-23 AHP Analysis with PV for Maintenance Information & Documentation Module of Company X

Maintenance Inf. & Doc. Module	Planning	Control	PV
Planning	1	2	**0.6667**
Control	1/2	1	0.3333

The PV values for *MID Planning* and *MID Control Sub-Modules* are 0.6667 and 0.3333, respectively. Therefore, the priority taken by Company X is to rectify aspects of *MID Planning Sub-Module* before attempting to improve aspects of *MID Control Sub-Module*. The analysis of KB rules reveals that some important information is unavailable or not up to date.

8.3.4.4 Company X: Summary of Level 3 – Maintenance Rules

The discussion of GAP analysis and AHP analysis for each module on *Level 3 – Maintenance Rules* has been completed. However, the most important step comes at this end. Referring to the flowchart in Figure 7-4, all modules under this level are compared in a pair-wise manner to find out which module should be prioritised before the others in order to get rectification. By using AHP method, the PV values for each module can be determined. The result of AHP analysis for *Level 3* is presented in Table 8-24, while the summary of AHP analysis for *Level 3 – Maintenance Rules* is presented in Table 8-25.

Table 8-24 AHP Analysis with PV for Level 3 – Maintenance Rules of Company X

Maintenance Rules Level	Maint. Policy	Maint. Organisation	Maint. Inf. & Doc.	PV
Maint. Policy	1	2	1/2	0.3119
Maint. Organisation	1/2	1	1/2	0.1976
Maint. Inf. & Doc.	2	2	1	**0.4905**

Table 8-25 Summary of AHP Analysis with PV for Level 3 – Maintenance Rules of Company X

<table>
<tr><th>KBIMSO Level</th><th>Module</th><th>PV</th><th>Sub-Module</th><th>PV</th></tr>
<tr><td rowspan="6">Level 3 Maintenance Rules</td><td rowspan="2">Maintenance Policy</td><td rowspan="2">0.3119</td><td>Planning</td><td>0.7500</td></tr>
<tr><td>Control</td><td>0.2500</td></tr>
<tr><td rowspan="2">Maintenance Organisation</td><td rowspan="2">0.1976</td><td>Planning</td><td>0.2500</td></tr>
<tr><td>Control</td><td>0.7500</td></tr>
<tr><td rowspan="2">Maintenance Inf. & Doc.</td><td rowspan="2">0.4905</td><td>Planning</td><td>0.6667</td></tr>
<tr><td>Control</td><td>0.3333</td></tr>
</table>

When PV values for all modules are sorted from the highest to the lowest, *Maintenance Information and Documentation Module* is appointed to get the priority of improvement before the other modules. It has PV value of 0.4905. Meanwhile, *Maintenance Policy Module* and *Maintenance Organisation Module* have PV values of 0.3119 and 0.1976, respectively. Focussing on *Maintenance*

Information and Documentation Module, the KBIMSO model then provides in more detail of which sub-module and aspects within such module should be prioritised to improve maintenance rules performance. By recalling the AHP analysis been conducted for each module, as summarised in Table 8-25, the prioritised sub-module in *Maintenance Information and Documentation Module* is *MID Planning Sub-Module*. The detailed recommendation for this level is compiled with other levels and discussed later in the Summary of Verification and Validation of the KBIMSO Model for Company X, in Section 8.4.1.

8.3.5 Company X: Level 4 – Maintenance Activities

Level 4 – Maintenance Activities is the second level in the *Maintenance Operations Stage*. It covers the variety of technical process required to complete maintenance tasks. This is considered very important to manage on the KBIMSO after maintenance rules are defined. However, maintenance activities should be performed in the most efficient way in order to meet the business goal. Maintenance activities are classified into four different activities, which are represented on modules. Those are *Repairing Activity Module*, *Retaining Activity Module*, *Modification Activity Module*, and *Design Activity Module*, as can be referred to Figure 7-8. To specify the use of that structure in Company X, the detailed structure of Level 4 is presented again in Figure 8-5.

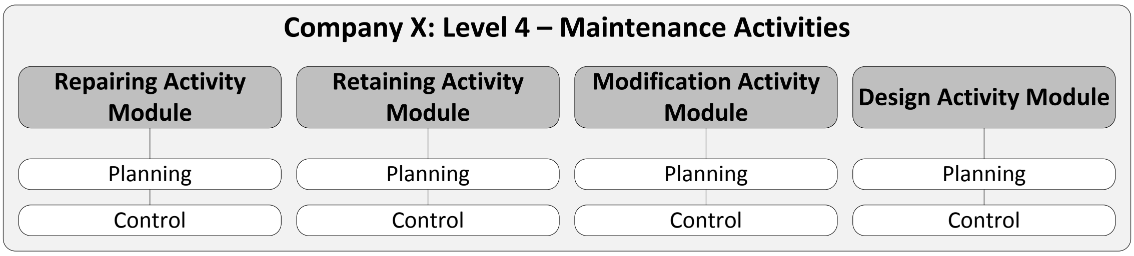


Figure 8-5 Company X: Detailed structure of Level 4 – Maintenance Activities

In this level, maintenance activities of KBIMSO assist Company X to identify sort of maintenance activities that have been conducted and precondition before executing it. This level also evaluates how the company performs the maintenance activities toward benchmarking. All maintenance activities discussed at this level are directed to the planned maintenance. Although Repairing Activity commonly corresponds to Corrective Maintenance, such activity in this module discusses the repairing of the detected failure on planned and scheduled maintenance. Retaining Activity encompasses a variety of activities on Preventive Maintenance and Predictive Maintenance. Meanwhile, Modification Activity and Design Activity adopt Aggressive Maintenance, which is rooted in Total Productive Maintenance (TPM) approach. Similar to previous modules within Maintenance Perspective, the modules in *Level 4 – Maintenance Activities* are built from two sub-modules, *Planning* and *Control*. However, the KB rules inside each sub-module are dedicatedly developed based on the modules' characteristics. Recapitulation of KB rules' response regarding this level on Company X is summarised in Table 8-26.

Table 8-26 Summary of GAP Analysis for Level 4 – Maintenance Activities of Company X

KBIMSO Level	Module	Sub-Module	Number of KB Rules	GAP Analysis for Company X										
				GP	BP	Problem Category (PC)								
						1	2	3	4	5	6	7	8	9
Level 4 Maintenance Perspective - Maintenance Activities	Repairing Activity	Planning	10	6	4	0	1	3	0	0	0	0	0	0
		Control	13	5	8	0	0	1	1	6	0	0	0	0
		Sub-Total	**23**	**11**	**12**	**0**	**1**	**4**	**1**	**6**	**0**	**0**	**0**	**0**
	Retaining Activity	Planning	25	20	5	0	0	5	0	0	0	0	0	0
		Control	13	6	7	0	0	1	2	4	0	0	0	0
		Sub-Total	**38**	**26**	**12**	**0**	**0**	**6**	**2**	**4**	**0**	**0**	**0**	**0**
	Modification Activity	Planning	11	3	8	0	0	6	0	2	0	0	0	0
		Control	6	2	4	0	0	1	1	2	0	0	0	0
		Sub-Total	**17**	**5**	**12**	**0**	**0**	**7**	**1**	**4**	**0**	**0**	**0**	**0**
	Design Activity	Planning	11	4	7	0	0	4	0	3	0	0	0	0
		Control	6	0	6	0	0	2	1	3	0	0	0	0
		Sub-Total	**17**	**4**	**13**	**0**	**0**	**6**	**1**	**6**	**0**	**0**	**0**	**0**
	Total		**95**	**46**	**49**	**0**	**1**	**23**	**5**	**20**	**0**	**0**	**0**	**0**

As shown in the table above, there are 239 KB rules developed in *Level 4 – Maintenance Activities*, with 49 of them are categorised as BPs. These BPs consist of 1 PC-2, 23 PC-3, 5 PC-4, and 20 PC-5. The largest number of problems is found in *Design Activity Module* that reveals 13 BPs (6 PC-3, 1 PC-4, and 6 PC-5). Although it seems to have proportional weight by having an almost similar number of BPs on all modules, the proportion of BPs towards total KB rules as well as the configuration of PCs on each module influences the priority of improvement which will be recommended. Facing this multi-variable decision making, a further AHP analysis is definitely required. As the beginning, AHP analysis is conducted to set the priority of sub-module on each module. In the end, the AHP analysis is directed to recommend which module should be rectified before the others under this level.

8.3.5.1 Company X: Level 4.1 – Repairing Activity Module

Referring to Table 8-26, *Repairing Activity (RepA) Module* contains 23 KB rules. From that total, Company X is identified to have 11 GPs and 12 BPs. This means there are 12 current conditions on repairing activity that cannot meet the prerequisite conditions. These gaps are classified as 1 PC-2, 4 PC-3, 1 PC-4, and 1 PC-5. Although *RepA Planning Sub-Module* has only 4 BPs, all of the BPs lie on the critical level (1 PC-2 and 3 PC-3). Meanwhile, *RepA Control Sub-Module* has 8 BPs yet they majority lie on the less critical level (1 PC-1, 1 PC-2, and 6 PC-5). To confirm of which sub-module that contributes more to maintenance performance, these sub-modules should be weighted and compared in a pair-wise manner through AHP analysis. The result is shown in Table 8-27.

Table 8-27 AHP Analysis with PV for Repairing Activity Module of Company X

Repairing Activity Module	Planning	Control	PV
Planning	1	2	**0.6667**
Control	1/2	1	0.3333

By determining the PV value of each sub-module, the priority of improvement goes to the highest PV value. Since PV value of *RepA Planning Sub-Module* is 0.6667, while PV value of *RepA Control Sub-Module* is 0.3333. *RepA Planning Sub-Module* requires improvement before *RepA Control Sub-Module*. The KB rules highlighted that Company X needs to consider the priority of repairing based on cost of failure and also provide procedures for repairing activity on some aspects.

8.3.5.2 Company X: Level 4.2 – Retaining Activity Module

Since retaining activity encompasses preventive and predictive maintenance, there are more KB rules generated on this module than on repairing activity. Referring to Table 8-26, *Retaining Activity (RetA) Module* contains 38 KB rules. From that total of KB rules examined on Company X, 26 KB rules are categorised as GPs and the rest of 12 KB rules are categorised as BPs. *RetA Control Sub-Module* has 7 BPs (1 PC-3, 2 PC-4, and 4 PC-5) and *RetA Planning Sub-Module* has 5 BPs on PC-3. AHP method is then applied to confirm recommendation based on PV values by considering the weight of KB rules and criticality of PCs. The result of AHP analysis of this module for Company X is presented in Table 8-28.

Table 8-28 AHP Analysis with PV for Retaining Activity Module of Company X

Retaining Activity Module	Planning	Control	PV
Planning	1	1/2	0.3333
Control	2	1	**0.6667**

Similar to the indication showed by GAP analysis, PV value of *RetA Control Sub-Module* is 0.6667, higher than PV value of *RetA Planning Sub-Module* of 0.3333. This result concludes that Company X needs to improve *RetA Control Sub-Module* before treating *RetA Planning Sub-Module*. By analysing the KB rules, the biggest problem appears in the way of optimising information for maintenance task scheduling.

8.3.5.3 Company X: Level 4.3 – Modification Activity Module

Referring again to Table 8-26, the total of KB rules generated on *Modification Activity (MoA) Module* is 17 KB rules. There are 5 KB rules counted as GPs and 12 KB rules as BPs. By focusing on BPs, there are 8 BPs found in *MoA Planning Sub-Module* and 4 BPs found in *MoA Control Sub-Module*. Those BPs lie on PC-3 to PC-5 which indicate quite important problems, but less critical. However, it is still necessary to provide priority between these sub-modules to set up the improvement plan. Furthermore, the weight of KB rules is included to achieve valid recommendation through AHP analysis. The result for Company X is shown in Table 8-29.

Table 8-29 AHP Analysis with PV for Modification Activity Module of Company X

Modification Activity Module	Planning	Control	PV
Planning	1	2	**0.6667**
Control	1/2	1	0.3333

By weighting the KB rules and attached GAP (in term of PC), the PV values are determined. In fact, PV value of *MoA Planning Sub-Module* is 0.6667, higher than PV value of *MoA Control Sub-Module*, 0.3333. This means that priority of improvement on modification activity for Company X is addressed to *Planning* aspects, especially on adapting TPM approach into modification activity (based on KB rules analysis).

8.3.5.4 Company X: Level 4.4 – Design Activity Module

This module is the last module in *Level 4 – Maintenance Activity*. Together with *Modification Activity Module*, this *Design Activity (DeA) Module* is considered as part of proactive maintenance which adopts TPM approach to the implementation. Referring again to Table 8-26, this module has 17 KB rules in total with the configuration of 4 GPs and 13 BPs. These BPs are distributed on both sub-modules. On *DeA Planning Sub-Module*, there are 7 BPs identified which are categorised into 4 PC-3 and 3 PC-5. Meanwhile, there are 6 BPs identified on *DeA Control Sub-Module* which are categorised into 6 PC-3, 1 PC-4, and 6 PC-5. Based on the number, *DeA Planning Sub-Module* has more BPs than *RetA Control Sub-Module*. However, based on weight and impact on maintenance performance, this formation might be changed based on PV values in order to set the improvement priority. The AHP analysis confirms the PV values of sub-modules as shown in Table 8-30.

Table 8-30 AHP Analysis with PV for Design Activity Module of Company X

Design Activity Module	Planning	Control	PV
Planning	1	1/2	0.3333
Control	2	1	**0.6667**

From the result of AHP analysis, PV value of *DeA Planning Sub-Module* is 0.3333 whilst PV value of *DeA Control Sub-Module* is 0.6667. Apparently, the recommendation of improvement is confirmed on *DeA Control Sub-Module*. The KB rules on this sub-module indicate that Company X needs to improve current performance of design activity.

8.3.5.5 Company X: Summary of Level 4 – Maintenance Activities

AHP analysis method in KBIMSO is applied separately under each level. By this, it means that each level is assisted to identify its critical area to maintenance performance. Initially, AHP analysis is deployed to determine the PV values of sub-modules under each module. The highest PV value represents the most problematic area on that module which requires priority of improvement. After analysing the modules, AHP method is used to analyse the level. In *Level 4 – Maintenance Activities*, AHP determines the PV value of each maintenance activity modules to figure out which maintenance activity should be prioritised to review and improve. The result of AHP analysis for *Level 4* is presented in Table 8-31, while the summary of AHP analysis for *Level 4 – Maintenance Activities* is presented in Table 8-32.

Table 8-31 AHP Analysis with PV for Level 4 – Maintenance Activities of Company X

Maintenance Activities Level	Repair	Retain	Modification	Design	PV
Repairing Activity	1	2	1/2	1/2	0.1872
Retaining Activity	1/2	1	1/3	1/3	0.1080
Modification Activity	2	3	1	1/2	0.2930
Design Activity	2	3	2	1	**0.4118**

Table 8-32 Summary of AHP Analysis with PV for Level 4 – Maintenance Activities of Company X

KBIMSO Level	**Module**	**PV**	**Sub-Module**	**PV**
Level 4 Maintenance Activities	Repairing Activity	0.1872	**Planning**	**0.6667**
			Control	0.3333
	Retaining Activity	0.1080	Planning	0.3333
			Control	**0.6667**
	Modification Activity	0.2930	**Planning**	**0.6667**
			Control	0.3333
	Design Activity	**0.4118**	Planning	0.3333
			Control	**0.6667**

From Table 8-31 it can be found that pair-wise comparison of AHP method determines the PV value of each module under *Level 4 – Maintenance Activities*. Sorted from the highest value, PV value of *Design Activity Module* is 0.4118, followed by *Modification Activity Module*, *Repairing Activity Module*, and *Retaining Activity Module* with PV values of 0.2930, 0.1872, and 0.1080, respectively. To understand which aspect on *Design Activity Module* should be improved, the AHP analysis of modules is recalled, as summarised in Table 8-32. On *Design Activity Module*, it is noticed that there are many KB rules on *DeA Control Sub-Module* cannot meet the prerequisite conditions (by having the highest PV value) than KB rules on *DeA Planning Sub-Module*. The detailed recommendation for this level is compiled with other levels and discussed later in the Summary of Verification and Validation of the KBIMSO Model for Company X, in Section 8.4.1.

8.3.6 Company X: Level 5 – Maintenance Resources

Level 5 – Maintenance Resources is the last level in KBIMSO. It also completes the last part of Maintenance Perspective on *Maintenance Operations Stage*. Maintenance as a particular system in a company requires system entities which are interconnected to build it up. Maintenance resources need to execute maintenance activities under clear maintenance rules. Since *Maintenance Rules Level* and *Maintenance Activities Level* have been verified and validated on the previous sections, this section focuses on verifying and validating *Maintenance Resources Level*. There are four modules at this level; *Maintenance Personnel Module*, *Maintenance Tools Module*, *Maintenance Material Module*, and *Maintenance ICT Module*, as can be referred to Figure 7-14. To specify the use of that structure in Company X, the detailed structure of Level 5 is shown again in Figure 8-6.

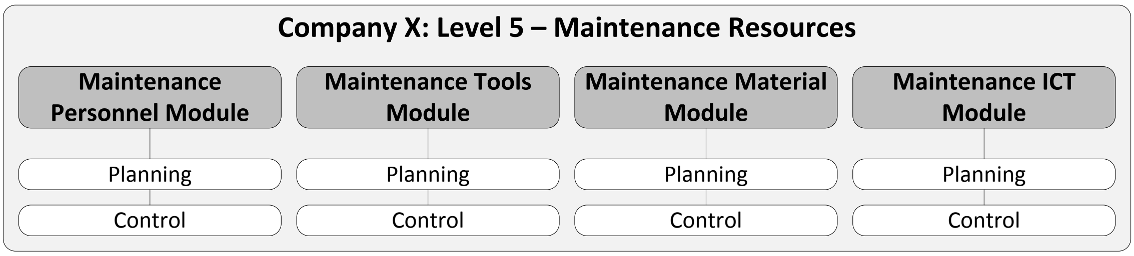


Figure 8-6 Company X: Detailed structure of Level 5 – Maintenance Resources

Those resources above are required by Company X to execute maintenance tasks. Considering the limitation of resources against the maintenance workload, Company X should wisely decide the priority of task executed, and how to maintain those resources to achieve the optimal maintenance performance. To get a consistent flow of KBIMSO model, the modules in this level also consist of two sub-modules; *Planning* and *Control*. *Planning Sub-Module* is directed to ensure that maintenance resources can be set effectively and efficiently in their best condition. Furthermore, *Control Sub-Module* evaluates the preparation made and rates the current performance towards benchmark. The recapitulation of KB rules' response regarding *Level 5 – Maintenance Resources* on Company X is summarised in Table 8-33.

Table 8-33 Summary of GAP Analysis for Level 5 – Maintenance Resource of Company X

KBIMSO Level	Module	Sub-Module	Number of KB Rules	GAP Analysis for Company X										
				GP	BP	Problem Category (PC)								
						1	2	3	4	5	6	7	8	9
Level 5 Maintenance Perspective - Maintenance Resources	Maintenance Personnel	Planning	25	21	4	0	2	1	0	1	0	0	0	0
		Control	16	6	10	0	0	3	2	5	0	0	0	0
		Sub-Total	**41**	**27**	**14**	**0**	**2**	**4**	**2**	**6**	**0**	**0**	**0**	**0**
	Maintenance Tools	Planning	7	4	3	0	1	2	0	0	0	0	0	0
		Control	10	4	6	0	0	0	2	4	0	0	0	0
		Sub-Total	**17**	**8**	**9**	**0**	**1**	**2**	**2**	**4**	**0**	**0**	**0**	**0**
	Maintenance Material	Planning	17	13	4	0	1	3	0	0	0	0	0	0
		Control	8	2	6	0	0	2	1	3	0	0	0	0
		Sub-Total	**25**	**15**	**10**	**0**	**1**	**5**	**1**	**3**	**0**	**0**	**0**	**0**
	Maintenance ICT	Planning	9	4	5	0	1	4	0	0	0	0	0	0
		Control	12	1	11	0	1	4	4	2	0	0	0	0
		Sub-Total	**21**	**5**	**16**	**0**	**2**	**8**	**4**	**2**	**0**	**0**	**0**	**0**
	Total		**104**	**55**	**49**	**0**	**6**	**19**	**9**	**15**	**0**	**0**	**0**	**0**

As shown in the table above, out of 104 KB rules, there are 55 GPs and 49 BPs. The BPs are further classified into PCs as follows: 6 PC-2, 19 PC-3, 9 PC-4, and 15 PC-5. The most problematic areas, represented by the number of BPs, are identified on *Maintenance ICT Module* and *Maintenance Personnel Module* with 16 BPs and 14 BPs, respectively. However, a stand-alone GAP analysis cannot always mention accurately the criticality of such module to the maintenance performance. Thus the priority of improvement should be carefully defined by weighting the PCs of a module and comparing them with the PCs of other modules. For this need, the KBIMSO model is integrated with AHP analysis. The priority under each module is discussed in the following sections.

8.3.6.1 Company X: Level 5.1 – Maintenance Personnel Module

Referring to Table 8-33, *Maintenance Personnel (MPers) Module* contains 41 KB rules. Out of the total of KB rules, there are 27 GPs and 14 BPs identified. Majority of BPs are detected on *MPers Control Sub-Module* by having 10 BPs (3PC-3, 2 PC-4, and 5 PC-5). This means that half of this BPs is classified on the important area while another half is classified on the less important area for maintenance performance of Company X. Meanwhile, *MPers Planning Sub-Module* collects 4 BPs (2 PC-2, 1 PC-3, and 1 PC-5). This finding expresses that *MPers Control Sub-Module* requires attention to review and improve than another sub-module.

However, to confirm this GAP analysis, AHP analysis is conducted by involving a pair-wise comparison and weight for priority. The calculation of PV values on AHP analysis can be seen in Table 8-34.

Table 8-34 AHP Analysis with PV for Maintenance Personnel Module of Company X

Maintenance Personnel Module	Planning	Control	PV
Planning	1	0.5	0.3333
Control	2	1	**0.6667**

The PV values for *MPers Planning Sub-Module* and *MPers Control Sub-Module* are 0.3333 and 0.6667, respectively. Since the highest PV value indicates the first priority to improve, it can be concluded that *Maintenance Personnel Module* has to prioritise *MPers Control Sub-Module* on its improvement plan. Particularly, Company X needs to pay more attention to staff training and written operation procedure.

8.3.6.2 Company X: Level 5.2 – Maintenance Tools Module

Out of 17 KB rules on *Maintenance Tools (MTools) Module*, referring to Table 8-33, 8 KB rules are categorised as GPs, and 9 KB rules are categorised as BPs. Level of PCs on that BPs varies from PC-2 to PC-5. On *MTools Planning Sub-Module*, the BPs are concentrated on the first four PC (important category) by having 1 PC-2 and 2 PC-3. Meanwhile, *MTools Control Sub-Module* has 2 PC-4 and 4 PC-5. Although *MTools Control Sub-Module* has more BPs than *MTools Planning Sub-Module*, AHP analysis is then required to compare these two sub-modules by considering the weight of their BPs. The result of AHP analysis is presented in Table 8-35 which show the PV values of each sub-module.

Table 8-35 AHP Analysis with PV for Maintenance Tools Module of Company X

Maintenance Tools Module	Planning	Control	PV
Planning	1	2	**0.6667**
Control	1/2	1	0.3333

This result leads to the recommendation of priority for Company X to manage its maintenance tools. In fact, PV value of *MTools Planning Sub-Module* is 0.6667, while PV value of *MTools Control Sub-Module* is 0.3333. Therefore, aspects of

MTools Planning Sub-Module should be prioritised to improve before taking any treatment for *MTools Control Sub-Module*. By looking down to set of KB rules, the opportunity to significantly improve maintenance performance on maintenance tools could be taken by ensuring tools availability to support maintenance tasks.

8.3.6.3 Company X: Level 5.3 – Maintenance Material Module

A total of 25 KB rules has been examined for *Maintenance Material (MMat) Module*, referring to Table 8-33. After collecting the response from the user of Company X, it can be tabulated that 15 KB rules are classified as GPs, whilst 10 KB rules are classified as BPs with different level of PCs. On *MMat Planning Sub-Module*, there are 4 KB rules represent the gap between current and prerequisite conditions. These gaps (BPs) are detected as 1 PC-2 and 3 PC-3. Meanwhile, on *MMat Control Sub-Module*, there are 6 BPs which are identified as 2 PC-3, 1 PC-4, and 3 PC-5. Considering the variation of PC level appointed into BPs, the process to decide the improvement priority is continued by using AHP analysis. The result of AHP analysis is shown in Table 8-36.

Table 8-36 AHP Analysis with PV for Maintenance Material Module of Company X

Maintenance Material Module	Planning	Control	PV
Planning	1	1/2	0.3333
Control	2	1	**0.6667**

PV value of *MMat Planning Sub-Module* is 0.3333, while PV value of *MMat Control Sub-Module* is 0.6667. This result assists the KBIMSO to recommend priority of improvement for Company X on *MMat Control Sub-Module*. Reviewing back to the KB rules on this sub-module, the problem is mostly caused by an incomplete part specification which leads to disturbing the maintenance process, both on identifying required part to use and stock.

8.3.6.4 Company X: Level 5.4 – Maintenance ICT Module

Maintenance ICT (MICT) Module is the final module for this level as well as for the KBIMSO model. Referring to Table 8-33, there are 21 KB rules generated on this module, but only 5 of them are categorised as GPs. The rest of 16 KB rules lie from PC-2 to PC-5. There are 5 BPs are found in *MICT Planning Sub-Module*. These BPs only refer to 1 PC-2 and 4 PC-3. But more BPs are found in *MICT Control Sub-Module*, which are 11 BPs with the classification of 1 PC-2, 4 PC-3, 4 PC-4, and 2 PC-5. To get an accurate assessment of which sub-module should be prioritised for improvement, AHP analysis is applied with the result presented in Table 8-37.

Table 8-37 AHP Analysis with PV for Maintenance ICT Module of Company X

Maintenance ICT Module	Planning	Control	PV
Planning	1	1/2	0.3333
Control	2	1	**0.6667**

PV value of *MICT Planning Sub-Module*, 0.3333, is lower than PV value of *MICT Control Sub-Module*, 0.6667. Thus, the KBIMSO recommends that Company X reviews and provides improvement plan for *Control* aspect of Maintenance ICT. The analysis of KB rules reveals that the problematic conditions are triggered by the commitment of using CMMS to support maintenance performance.

8.3.6.5 Company X: Summary of Level 5 – Maintenance Resources

Similar to the process done on the other levels of KBIMSO model, the discussion of this section is intended to finalise the AHP analysis on *Level 5 – Maintenance Resources*. The PV values are then used to propose the recommendation of improvement of module and sub-module under the level. The result of AHP analysis for *Level 5* is presented in Table 8-38, while the summary of AHP analysis for *Level 5 – Maintenance Resources* is presented in Table 8-39.

Table 8-38 AHP Analysis with PV for Level 5 – Maintenance Resources of Company X

Maintenance Resources Level	Personnel	Tools	Material	ICT	PV
Personnel	1	1/2	1/2	1/3	0.1202
Tools	2	1	2	1/2	0.2596
Material	2	1/2	1	1/3	0.1707
ICT	3	2	3	1	**0.4495**

Table 8-39 Summary of AHP Analysis with PV for Level 5 – Maintenance Resources of Company X

KBIMSO Level	Module	PV	Sub-Module	PV
Level 5 Maintenance Resources	Maintenance Personnel	0.1202	Planning	0.3333
			Control	**0.6667**
	Maintenance Tools	0.2596	**Planning**	**0.6667**
			Control	0.3333
	Maintenance Material	0.1707	Planning	0.3333
			Control	**0.6667**
	Maintenance ICT	**0.4495**	Planning	0.3333
			Control	**0.6667**

Table 8-38 shows the PV values of modules on *Maintenance Resources Level*. PV values for *Personnel, Tools, Material* and *ICT* are 0.1202, 0.2596, 0.1707, and 0.4495, respectively. By this, *Maintenance ICT Module* is identified to have the highest PV value. Considering that current condition on this module causes maintenance performs under the benchmark, this *Maintenance ICT Module* is recommended to be evaluated and improved before the other modules on this level. On *Maintenance ICT Module* itself, the most critical problem is identified by retrieving the result of AHP analysis of modules, as summarised in Table 8-39. The highest PV value on this module is *MICT Control Sub-Module*. The detailed recommendation for this level is compiled with other levels and discussed later in the Summary of Verification and Validation of the KBIMSO Model for Company X, in Section 8.4.1.

8.4 Verification and Validation Summary of KBIMSO Based on the Industrial Data

The detailed process of verification and validation of the KBIMSO model for each level has been discussed in Section 8.3. This section aims to summarise overall result of verification and validation of the KBIMSO model. Furthermore, this summary is a preliminary to detail the recommendation proposed to the companies based on their current conditions which are represented by the users' response.

8.4.1 Summary of Verification and Validation of the KBIMSO Model for Company X

Based on the response of users from Company X, GAP analysis which has been conducted for all levels of KBIMSO is summarised as presented in Table 8-40. A total of 1006 KB rules is examined for Company X to find out the current performance of maintenance function. Out of that total, 642 KB rules are categorised as Good Point (GPs) whilst 364 KB rules are categorised as Bad Points (BPs). This means that maintenance performance of Company X can reach 64% of assigned benchmark standard. In another word, maintenance performance of Company X is 36% lower than the assigned benchmark standard. Since the critical problems are defined as major problems which lie from PC-1 to PC-4, the rest of PCs (PC-5 to PC-9) are defined as minor problems. This grouping identifies that 27% of BPs found in Company X is categorised as major problems (critical) and 9% of BPs are categorised as minor problems. In more detail, the proportion of BPs (with the composition of major vs. minor problem) in *Level 1* and *Level 2* (*Strategic Stage*) of the KBIMSO is 29% (27:2) and 35% (24:11), respectively. Meanwhile, the proportion of BPs in *Level 3*, *Level 4*, and *Level 5* (*Maintenance Operations Stage*) of the KBIMSO is 40% (27:13), 52% (31:21), and 47% (33:14), respectively.

Table 8-40 Summary of GAP Analysis of Company X

KBIMSO Level	Module	Number of KB Rules	GAP Analysis for Company X										
			GP	BP	Problem Category (PC)								
					1	2	3	4	5	6	7	8	9
Level 1 Business Perspective	Company Statement Analysis	35	26	9	0	3	3	2	1	0	0	0	0
	Financial Analysis	52	33	19	0	9	10	0	0	0	0	0	0
	Customer Analysis	89	59	30	12	8	5	5	0	0	0	0	0
	Internal Business Process Analysis	119	87	32	6	14	9	3	0	0	0	0	0
	Learning & Growth Analysis	88	67	21	2	6	2	4	5	1	1	0	0
	Total	**383**	**272**	**111**	**20**	**40**	**29**	**14**	**6**	**1**	**1**	**0**	**0**
	Percentage (%)		**71**	**29**	**27**				**2**				
Level 2 Manufacturing Perspective	Manufacturing Equipment	83	45	38	9	3	10	7	8	1	0	0	0
	Manufacturing Process	124	90	34	5	5	7	4	9	1	1	2	0
	Process Quality	81	52	29	8	3	7	2	8	1	0	0	0
	Total	**288**	**187**	**101**	**22**	**11**	**24**	**13**	**25**	**3**	**1**	**2**	**0**
	Percentage (%)		**65**	**35**	**24**				**11**				
Level 3 Maintenance Rules	Maintenance Policy	81	56	25	5	3	9	3	2	1	1	1	0
	Maintenance Organisation	28	12	16	0	0	3	4	7	0	1	0	1
	Maintenance Information & Documentation	27	14	13	3	4	1	2	3	0	0	0	0
	Total	**136**	**82**	**54**	**8**	**7**	**13**	**9**	**12**	**1**	**2**	**1**	**1**
	Percentage (%)		**60**	**40**	**27**				**13**				
Level 4 Maintenance Activities	Repair Activity	23	11	12	0	1	4	1	6	0	0	0	0
	Retain Activity	38	26	12	0	0	6	2	4	0	0	0	0
	Modification Activity	17	5	12	0	0	7	1	4	0	0	0	0
	Design Activity	17	4	13	0	0	6	1	6	0	0	0	0
	Total	**95**	**46**	**49**	**0**	**1**	**23**	**5**	**20**	**0**	**0**	**0**	**0**
	Percentage (%)		**48**	**52**	**31**				**21**				
Level 5 Maintenance Resources	Maintenance Personnel	41	27	14	0	2	4	2	6	0	0	0	0
	Maintenance Tools	17	8	9	0	1	2	2	4	0	0	0	0
	Maintenance Material	25	15	10	0	1	5	1	3	0	0	0	0
	Maintenance ICT	21	5	16	0	2	8	4	2	0	0	0	0
	Total	**104**	**55**	**49**	**0**	**6**	**19**	**9**	**15**	**0**	**0**	**0**	**0**
	Percentage (%)		**53**	**47**	**33**				**14**				
Grand Total		**1006**	**642**	**364**	**50**	**65**	**108**	**50**	**78**	**5**	**4**	**3**	**1**
Percentage (%)			**64**	**36**	**27**				**9**				

After recapitulating the response of user from Company X and identifying the criticality of KB rules through GAP analysis (PC description and rating), the KBIMSO provides a recommendation for improvement through AHP analysis. The sub-modules and modules specified on KBIMSO model are compared under each level to identify the highest PV value among them and to decide which problem should be solved at the first time. Company X needs to emphasise its improvement plan on those prioritised modules and sub-modules to close the gap toward the benchmarks. The PV values of AHP analysis for all levels of KBIMSO are summarised as presented in Table 8-41. This is retrieved from the AHP analysis result which has been discussed in the previous section. To figure out the whole picture of KBIMSO recommendation for Company X across all levels, the KBIMSO structure is presented with the prioritised modules and sub-modules highlighted on, as depicted in Figure 8-7.

Table 8-41 Summary of AHP Analysis with PV value of Company X

KBIMSO Level	Module	PV	Sub-Module	PV
Level 1 Business Perspective	Company Statement Analysis	0.1274	Value Socialisation	0.3333
			Value Integration	**0.6667**
	Financial Analysis	0.2357	Leverage Ratio	0.1676
			Liquidity Ratio	0.1171
			Efficiency Ratio	**0.4841**
			Profitability Ratio	0.2311
	Customer Analysis	**0.3611**	**Customer Satisfaction**	**0.7500**
			Market Share	0.2500
	Internal Business Process Analysis	0.1801	**Product Development**	**0.6667**
			After-sale Service	0.3333
	Learning & Growth Analysis	0.0957	**Employee Engagement**	**0.6667**
			Social & Environmental Issue	0.3333
Level 2 Manufacturing Perspective	**Manufacturing Equipment**	**0.4905**	**Organisational Support**	**0.4905**
			Planning	0.3119
			Control	0.1976
	Manufacturing Process	0.1976	**Organisational Support**	**0.4905**
			Planning	0.1976
			Control	0.3119
	Process Quality	0.3119	**Organisational Support**	**0.5889**
			Planning	0.1593
			Control	0.2519
Level 3 Maintenance Rules	Maintenance Policy	0.3119	**Planning**	**0.7500**
			Control	0.2500
	Maintenance Organisation	0.1976	Planning	0.2500
			Control	**0.7500**
	Maintenance Inf. & Doc.	**0.4905**	**Planning**	**0.6667**
			Control	0.3333
Level 4 Maintenance Activities	Repairing Activity	0.1872	**Planning**	**0.6667**
			Control	0.3333
	Retaining Activity	0.1080	Planning	0.3333
			Control	**0.6667**
	Modification Activity	0.2930	**Planning**	**0.6667**
			Control	0.3333
	Design Activity	**0.4118**	Planning	0.3333
			Control	**0.6667**
Level 5 Maintenance Resources	Maintenance Personnel	0.1202	Planning	0.3333
			Control	**0.6667**
	Maintenance Tools	0.2596	**Planning**	**0.6667**
			Control	0.3333
	Maintenance Material	0.1707	Planning	0.3333
			Control	**0.6667**
	Maintenance ICT	**0.4495**	Planning	0.3333
			Control	**0.6667**

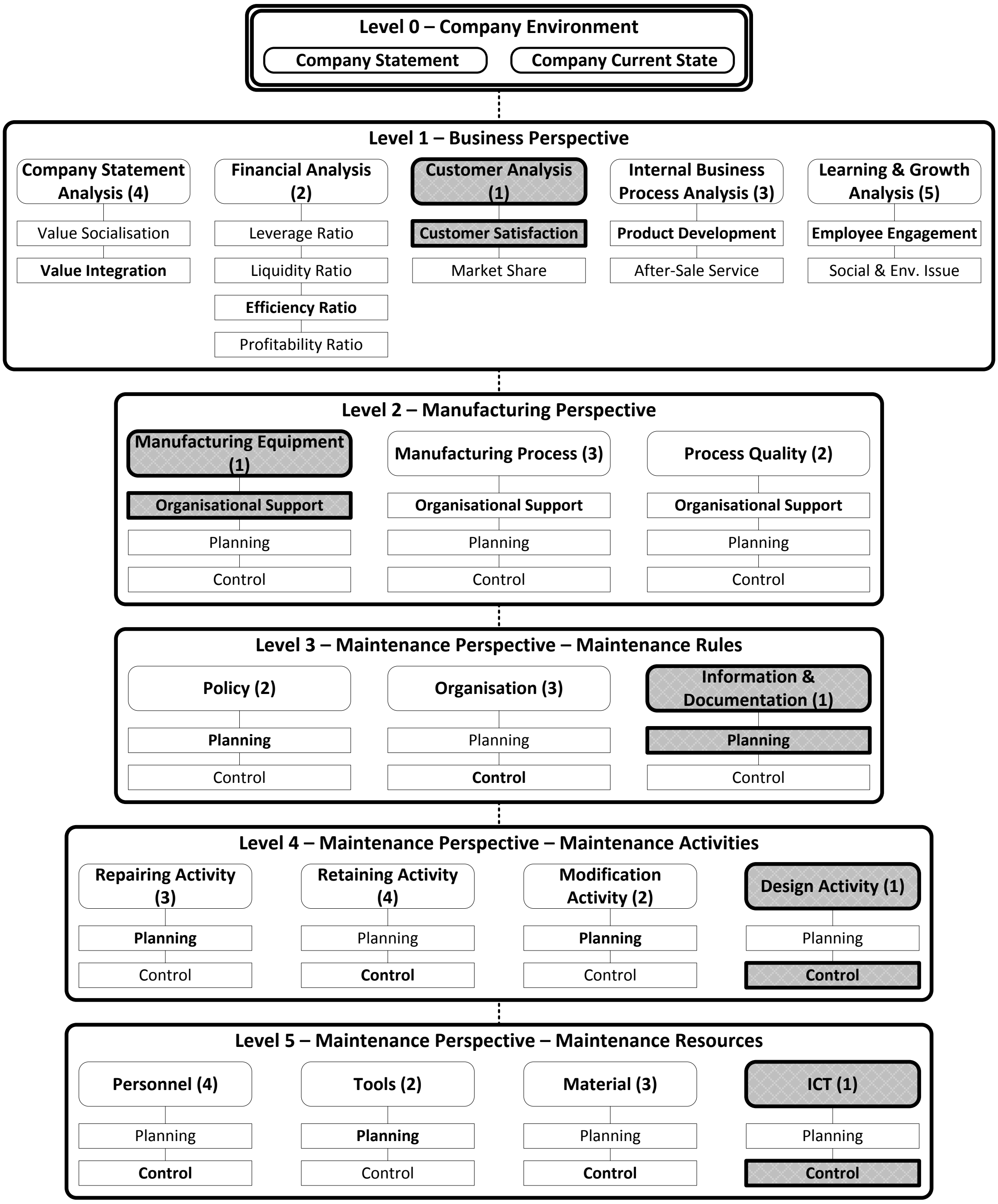


Figure 8-7 The priority improvement recommendation for Company X based on KB System – GAP – AHP analysis

Figure 8-7 shows the first priority of improvement that should be taken simultaneously across all levels by Company X in order to improve maintenance performance. Furthermore, this recommendation is traced back to the KB rules on the sub-modules and modules on each level to list the recommended activities should be taken by the company to improve its maintenance performance, as summarised in Figure 8-8. For the sake of brevity and to emphasise the importance of those KB rules to the system performance, only KB rules with PC-1 to PC-4 are presented.

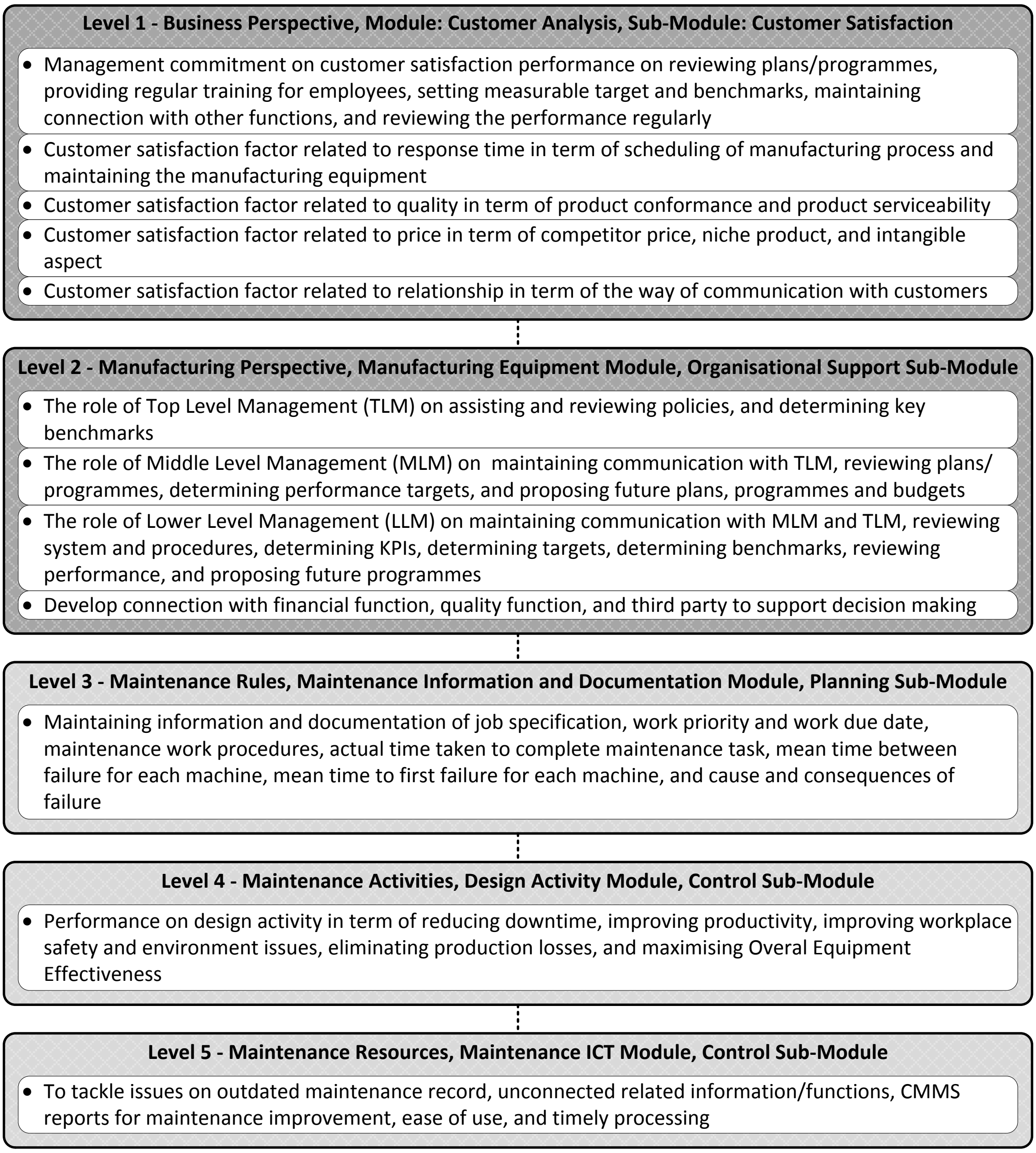


Figure 8-8 The summary of KBIMSO recommendation based on KB rules for Company X

The KB rules are always presented as the prerequisite conditions (Good Point). Thus the conditions mentioned in Figure 8-8 indicate the prerequisite conditions which cannot properly be achieved and should be prioritised to get improvement. On *Strategic Stage*, rectification for Company X on *Level 1 – Business Perspective* is prioritised on *Customer Analysis Module*, specifically on *Customer Satisfaction Sub-Module*. Besides evaluating the commitment of management to achieve customer satisfaction, the company should pay more attention to improve particular customer satisfaction factors related to response time, quality, cost, and intangible aspect. Meanwhile, the improvement in *Level 2 – Manufacturing Perspective* is prioritised on *Manufacturing Equipment Module*, specifically on *ME Organisational Support Sub-Module*. It means that the main problem on maintaining manufacturing equipment is related to the role of different management levels, particularly in determining key benchmarks which is useful to set the target of performance. In addition, an intense communication with other related functions could ensure the validity of input for decision making.

For *Maintenance Operations Stage*, there are three levels built it up. Improvement plan for Company X on *Level 3 – Maintenance Rules* should be prioritised on *Information and Documentation Module*, with special attention on *MID Planning Sub-Module*. This indicates that Company X is careless on information availability to support maintenance tasks and causes underperformance compared to other aspects under *Maintenance Rules Level*. The rectification of *Level 4 – Maintenance Activities* is mainly focussed on *Maintenance Design Activity*, particularly on *DeA Control Sub-Module*. By having the biggest problematic area on *DeA Control Sub-Module*, it indicates that design activity has not been utilised properly. However, this activity approach is still new and needs more attention and improvement to practice. On *Level 5 – Maintenance Resources*, improvement priority is directed to *Maintenance ICT Module* with special attention on *MICT Control Sub-Module*. The fragmented information sources take a long time to make a decision. To deal with this issue, the company needs to increase the awareness about the importance of integrated and updated information to smooth maintenance activities by facilitating a CMMS tool which is operated by the trained operators.

8.4.2 Summary of Verification and Validation of the KBIMSO Model for Company Y

To get another perception of how the KBIMSO model works in the automotive environment, verification and validation process are attempted in another automotive company, which is Company Y. For sake of brevity, the detailed discussion of user response from Company Y is not presented in this thesis. However, the structure and steps conducted are similar to the ones in Company

X. The tabulation of result and summary of GAP analysis and AHP analysis for each level are attached in Appendix B. Meanwhile, the result of GAP analysis which has been conducted for all levels of KBIMSO is summarised as presented in Table 8-42.

Table 8-42 Summary of GAP Analysis for Company Y

KBIMSO Level	Module	Number of KB Rules	GAP Analysis for Company Y										
			GP	BP	Problem Category (PC)								
					1	2	3	4	5	6	7	8	9
Level 1 Business Perspective	Company Statement Analysis	35	29	6	0	2	2	2	0	0	0	0	0
	Financial Analysis	52	33	19	0	9	10	0	0	0	0	0	0
	Customer Analysis	89	62	27	5	10	3	1	4	0	0	4	0
	Internal Business Process Analysis	119	79	40	4	17	14	5	0	0	0	0	0
	Learning & Growth Analysis	88	66	22	3	5	2	3	7	2	0	0	0
	Total	383	269	114	12	43	31	11	11	2	0	4	0
	Percentage (%)		70	30	25				4				
Level 2 Manufacturing Perspective	Manufacturing Equipment	83	49	34	3	7	10	6	7	1	0	0	0
	Manufacturing Process	124	98	26	3	3	5	3	7	1	1	3	0
	Process Quality	81	47	34	7	5	9	3	9	1	0	0	0
	Total	288	194	94	13	15	24	12	23	3	1	3	0
	Percentage (%)		67	33	22				10				
Level 3 Maintenance Rules	Maintenance Policy	81	50	31	3	5	11	4	4	1	1	2	0
	Maintenance Organisation	28	13	15	0	2	3	2	4	0	0	0	4
	Maintenance Information & Documentation	27	17	10	2	3	3	1	1	0	0	0	0
	Total	136	80	56	5	10	17	7	9	1	1	2	4
	Percentage (%)		59	41	29				13				
Level 4 Maintenance Activities	Repair Activity	23	8	15	0	3	4	1	7	0	0	0	0
	Retain Activity	38	26	12	0	0	6	2	4	0	0	0	0
	Modification Activity	17	9	8	0	0	2	0	6	0	0	0	0
	Design Activity	17	11	6	0	0	0	1	5	0	0	0	0
	Total	95	54	41	0	3	12	4	22	0	0	0	0
	Percentage (%)		57	43	20				23				
Level 5 Maintenance Resources	Maintenance Personnel	41	32	9	0	3	3	0	3	0	0	0	0
	Maintenance Tools	17	8	9	0	2	2	2	3	0	0	0	0
	Maintenance Material	25	16	9	0	0	5	1	3	0	0	0	0
	Maintenance ICT	21	8	13	0	6	6	1	0	0	0	0	0
	Total	104	64	40	0	11	16	4	9	0	0	0	0
	Percentage (%)		62	38	30				9				
Grand Total		1006	661	345	30	82	100	38	74	6	2	9	4
Percentage (%)			66	34	25				9				

A total of 1006 KB rules is examined for Company Y to find out the current performance of maintenance function. Out of that total, 661 KB rules are categorised as Good Point (GPs) whilst 345 KB rules are categorised as Bad Points (BPs). This means that maintenance performance of Company Y can reach 66% of assigned benchmark standard. In another word, maintenance performance of Company Y is 34% lower than the assigned benchmark standard. Since the critical problems are defined as major problems which lie from PC-1 to PC-4, the rest of PCs (PC-5 to PC-9) are defined as minor problems. This grouping identifies that 25% of BPs found in Company Y are categorised as major problems (critical) and 9% of BPs are categorised as minor problems. In more detail, the proportion of BPs (with the composition of major vs. minor problem) in *Level 1* and *Level 2* (*Strategic Stage*) of the KBIMSO is 30% (25:4) and 33% (22:10), respectively. Meanwhile, the proportion of BPs in *Level 3*, *Level 4*, and *Level 5* (*Maintenance Operations Stage*) of the KBIMSO are 41% (29:13), 43% (20:23), and 38% (30:9), respectively.

After recapitulating the response of user from Company Y and identifying the criticality of KB rules through GAP analysis (PC description and rating), the KBIMSO provides a recommendation for improvement through AHP analysis. The sub-modules and modules specified on KBIMSO model are compared under each level to identify the highest PV value among them and to decide which problem should be solved at the first time. Company Y needs to emphasise its improvement plan on those prioritised modules and sub-modules to close the gap toward the benchmarks. The PV values of AHP analysis for all levels of KBIMSO are summarised as presented in Table 8-43. Meanwhile, to figure out the whole picture of KBIMSO recommendation for Company X across all levels, the KBIMSO structure is presented with the prioritised modules and sub-modules highlighted on, as depicted in Figure 8-9.

Table 8-43 Summary of AHP Analysis with PV value for Company Y

KBIMSO Level	Module	PV	Sub-Module	PV
Level 1 Business Perspective	Company Statement Analysis	0.1078	Value Socialisation	0.3333
			Value Integration	**0.6667**
	Financial Analysis	0.2422	Leverage Ratio	0.1676
			Liquidity Ratio	0.1171
			Efficiency Ratio	**0.4841**
			Profitability Ratio	0.2311
	Customer Analysis	0.1867	**Customer Satisfaction**	**0.6667**
			Market Share	0.3333
	Internal Business Process Analysis	**0.3200**	**Product Development**	**0.6667**
			After-sale Service	0.3333
	Learning & Growth Analysis	0.1433	**Employee Engagement**	**0.6667**
			Social & Environmental Issue	0.3333
Level 2 Manufacturing Perspective	Manufacturing Equipment	0.2973	**Organisational Support**	**0.3338**
			Planning	0.1416
			Control	0.5247
	Manufacturing Process	0.1638	Organisational Support	0.1976
			Planning	**0.4905**
			Control	0.3119
	Process Quality	**0.5390**	**Organisational Support**	**0.4905**
			Planning	0.1976
			Control	0.3119
Level 3 Maintenance Rules	Maintenance Policy	0.3119	**Planning**	**0.6667**
			Control	0.3333
	Maintenance Organisation	0.1976	Planning	0.2500
			Control	**0.7500**
	Maintenance Inf. & Doc.	**0.4905**	Planning	0.3333
			Control	**0.6667**
Level 4 Maintenance Activities	**Repairing Activity**	**0.4168**	**Planning**	**0.7500**
			Control	0.2500
	Retaining Activity	0.1928	Planning	0.3333
			Control	**0.6667**
	Modification Activity	0.2695	Planning	0.2500
			Control	**0.7500**
	Design Activity	0.1209	Planning	0.2500
			Control	**0.7500**
Level 5 Maintenance Resources	Maintenance Personnel	0.1202	Planning	0.3333
			Control	**0.6667**
	Maintenance Tools	0.2596	Planning	0.3333
			Control	**0.6667**
	Maintenance Material	0.1707	Planning	0.3333
			Control	**0.6667**
	Maintenance ICT	**0.4495**	Planning	0.3333
			Control	**0.6667**

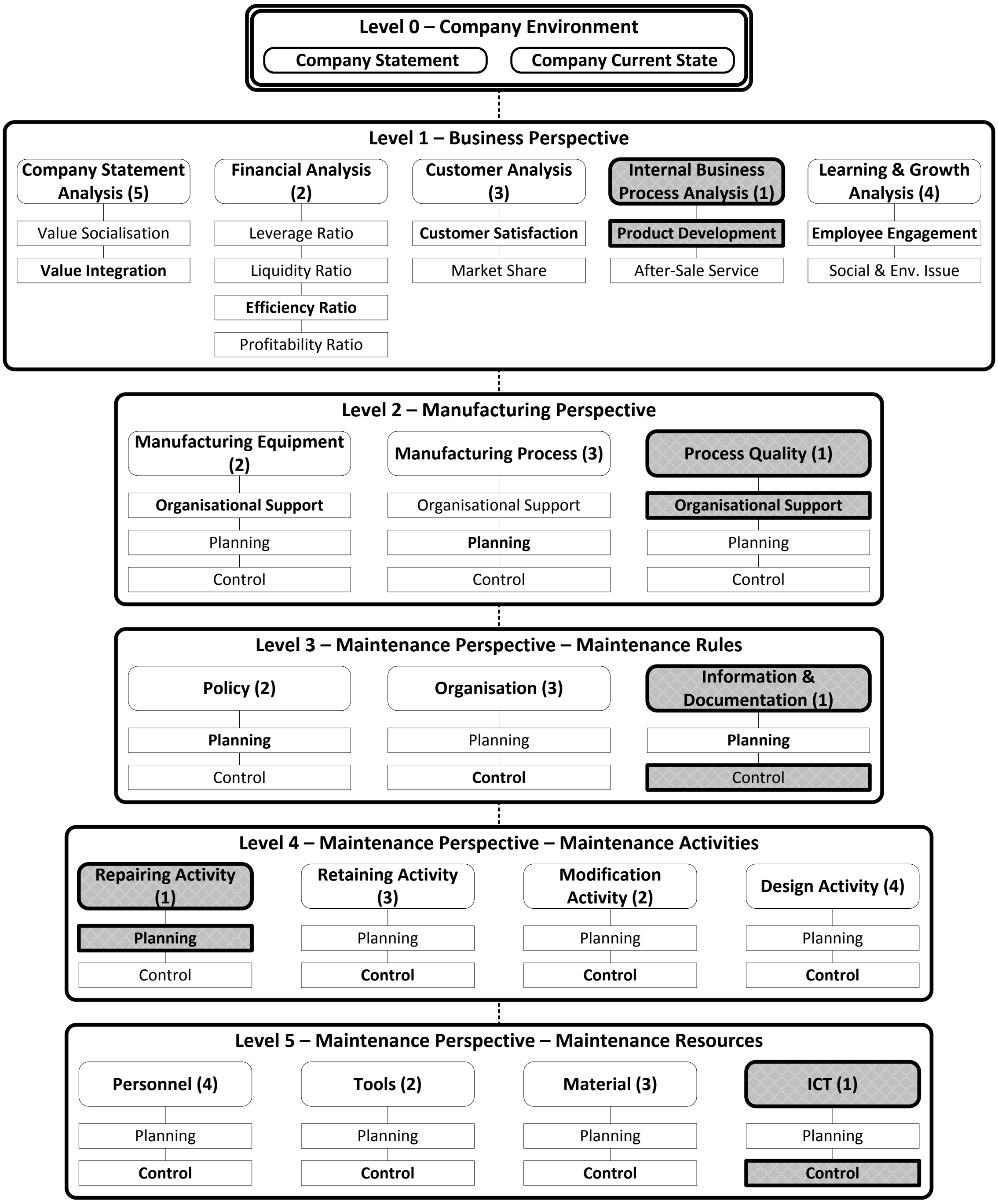


Figure 8-9 The priority improvement recommendation for Company Y based on KB System – GAP – AHP analysis

Figure 8-9 shows the first priority of improvement that should be taken simultaneously by Company Y across all levels in order to improve maintenance performance. Furthermore, this recommendation is traced back to the KB rules on the sub-modules and modules on each level to list the recommended activities should be taken by the company to improve its maintenance performance, as summarised in Figure 8-10. For the sake of brevity and to emphasise the importance of those KB rules to the system performance, only KB rules with PC-1 to PC-4 are presented.

Level 1 - Business Perspective, Module: IBP Analysis, Sub-Module: Product Development

- Management commitment on Customer Satisfaction performance on reviewing plans/programmes, setting measurable target and benchmarks, taking feedback for evaluation, maintaining connection with other related functions, communicating programmes and evaluation to the organisation
- The company is aware of its competitors and their capabilities, value proposition of their products or services, and their marketing strategy
- For reducing cycle time on product innovation, the company takes into account on developing a supporting system to enable iteration of development process and to enable cross functional integration, engaging with research centres, universities, and the new technology
- For increasing quality on product innovation, the company takes into account on facilitating collaboration between internal functions and suppliers/customers, engaging with research centres, universities, and the new methodologies
- For reducing cost on product innovation, the company takes into account on engaging with the new methodologies

Level 2 - Manufacturing Perspective, Module: Process Quality, Sub-Module: Organisational Support

- The role of Top Level Management (TLM) on reviewing programmes, communicating policies, and determining key benchmarks
- The role of Middle Level Management (MLM) on maintaining communication with TLM, assisting LLM, reviewing system and procedures, determining budget, key benchmarks and performance targets
- The role of Lower Level Management (LLM) on reviewing plans and programmes, reviewing system and procedures, determining KPIs and performance target, reviewing performance measurement, and providing feedback
- Develop connection with marketing function, and third party (supplier and customer)

Level 3 - Maintenance Rules, Module: Maintenance Information and Documentation, Sub-Module: Control

- Performance of maintenance information and documentation in term of updated regularly, accessible to those who require it to complete their task, synchronised in digital version for ease of use, maintained on a network system, and integrated with organisational performance management information system

Level 4 - Maintenance Activities, Module: Repairing Activity, Sub-Module: Planning

- Repairing activity is considered as minor maintenance activity and part of preventive maintenance
- To perform repair activity, the company has priority classification related to the risk of failure and the cost of failure
- The company have formal procedures to minimise time of corrective maintenance through locating the failure within the system to a specific item/equipment, recognising the existence of failure, and diagnosing the item/equipment to identify specific failed part/component

Level 5 - Maintenance Resources, Module: Maintenance ICT, Sub-Module: Control

- To tackle issue on outdated maintenance record, unconnected related information/functions, and inadequate training for maintenance planners and engineers in using CMMS
- Performance of maintenance ICT in term of reliability, accuracy, security, and ease of use

Figure 8-10 The summary of KBIMSO recommendation based on KB rules for Company Y

On *Strategic Stage*, rectification for Company Y on *Level 1 – Business Perspective* is prioritised on *Internal Business Process Analysis Module*, specifically on *Product Development Sub-Module*. The KB rules reveal that management commitment becomes the first task should be evaluated which is majority related to setting performance target and evaluation. Also, coordination with other related functions is required to support decision making. Furthermore, the company has to try the new approach for product development in order to reduce response time, increase quality, and reduce cost. Overall, the company has not engaged with an external research centre or university to develop a new methodology on product development process. Meanwhile, the improvement in *Level 2 – Manufacturing Perspective* is prioritised on *Manufacturing Process Quality Module*, specifically on *PQ Organisational Support Sub-Module*. Again, the role of different management levels is the priority to be evaluated, particularly on the contribution of each level to set benchmark and target towards performance, as well as improving communication from Top Level to Lower Level Management.

On *Maintenance Operations Stage*, the improvement plan for Company Y on *Level 3 – Maintenance Rules* should be prioritised on *Information and Documentation Module*, with special attention on *MID Control Sub-Module*. By reviewing the rules on maintenance information and documentation, the performance improvement could be obtained by assuring the information is always valid and easy to retrieve. The rectification of *Level 4 – Maintenance Activities* is mainly focussed on *Maintenance Repair Activity*, particularly on *RepA Planning Sub-Module*. This condition reveals that Company Y needs to reflect its corrective maintenance practice. To reduce unexpected repair activity, this company has to simultaneously classify the critically of its equipment and provide formal procedures of fault finding. On *Level 5 – Maintenance Resources*, improvement priority is directed to *Maintenance ICT Module* with first attention on *MICT Control Sub-Module*. The condition where Company Y could not get the full benefit of CMMS could be tackled by providing adequate training to utilise more CMMS features and developing a culture of which each person is responsible to provide valid information.

8.4.3 Gap Relationship Analysis of KBIMSO Validation

Since the research is specialised in the automotive industry, the gap relationship between these two companies could be examined to give the insight of how certain automotive companies perform their maintenance function to run the business. Considering that both of the companies are running in the same country and being managed by one parent company, the result might describe the management style and corporate culture which influence the organisation. Furthermore, discussing this gap relationship will assist in identifying the strength and drawback of one company towards another. The analysis is conducted based on the recapitulation of GAP analysis and AHP analysis on both companies, as presented in Table 8-44 and Table 8-45.

On the *Strategic Stage*, these companies indicate that they have quite similar business performance. Referring to Table 8-44, on all modules of *Level 1 – Business Perspective*, Company X and Y face critical problems on the same sub-modules, yet having a different combination of PCs. For example, on Company X, there are 9 BPs (3 PC-2, 3 PC-3, 2 PC-4, and 1 PC-5) are found in *Company Statement Analysis Module*. Meanwhile, on company Y, there are 6 BPs (2 PC-2, 2 PC-3, and 2 PC-4) are found in this module. Both of them are concentrated on *Value Socialisation Sub-Module*. Both companies have critical problems on sub-modules of *Efficiency Ratio*, *Customer Satisfaction*, *Product Development*, and *Employee Engagement*, which refer to sort of modules of *Financial Analysis*, *Customer Analysis*, *Internal Business Process Analysis*, and *Learning and Growth Analysis* modules, respectively. Since having a different configuration of PCs, the companies could support and learn each other to deal with the KB rules they are still absent in. However, the weight of total PCs on each module influences PV values in AHP analysis which then lead these companies to the different recommendation. As referred to Table 8-45, the recommendation for Company X is to close the gaps of KB rules on *Customer Satisfaction Sub-Module* in *Customer Analysis Module*, while for Company Y is to improve *Product Development Sub-Module* in *Internal Business Process Analysis Module*.

Table 8-44 Summary of GAP analysis of KBIMSO validation

KBIMSO Level	Module	Sub-Module	Number of KB Rules	GAP Analysis for Company X											GAP Analysis for Company Y										
				GP	BP	Problem Category (PC)									GP	BP	Problem Category (PC)								
						1	2	3	4	5	6	7	8	9			1	2	3	4	5	6	7	8	9
Level 1 Business Perspective	Company Statement Analysis	Value Socialisation	21	15	6	0	0	3	2	1	0	0	0	0	17	4	0	0	2	2	0	0	0	0	0
		Value Integration	14	11	3	0	3	0	0	0	0	0	0	0	12	2	0	2	0	0	0	0	0	0	0
		Sub-Total	**35**	**26**	**9**	**0**	**3**	**3**	**2**	**1**	**0**	**0**	**0**	**0**	**29**	**6**	**0**	**2**	**2**	**2**	**0**	**0**	**0**	**0**	**0**
	Financial Analysis	Leverage Ratio	15	10	5	0	1	4	0	0	0	0	0	0	10	5	0	1	4	0	0	0	0	0	0
		Liquidity Ratio	15	11	4	0	1	3	0	0	0	0	0	0	11	4	0	1	3	0	0	0	0	0	0
		Efficiency Ratio	6	2	4	0	3	1	0	0	0	0	0	0	2	4	0	3	1	0	0	0	0	0	0
		Profitability Ratio	16	10	6	0	4	2	0	0	0	0	0	0	10	6	0	4	2	0	0	0	0	0	0
		Sub-Total	**52**	**33**	**19**	**0**	**9**	**10**	**0**	**0**	**0**	**0**	**0**	**0**	**33**	**19**	**0**	**9**	**10**	**0**	**0**	**0**	**0**	**0**	**0**
	Customer Analysis	Customer Satisfaction	70	46	24	12	8	3	1	0	0	0	0	0	52	18	5	9	3	1	0	0	0	0	0
		Market Share	19	13	6	0	0	2	4	0	0	0	0	0	10	9	0	1	0	0	4	0	0	4	0
		Sub-Total	**89**	**59**	**30**	**12**	**8**	**5**	**5**	**0**	**0**	**0**	**0**	**0**	**62**	**27**	**5**	**10**	**3**	**1**	**4**	**0**	**0**	**4**	**0**
	Internal Business Process Analysis	Product Development	73	49	24	5	11	7	1	0	0	0	0	0	46	27	2	13	11	1	0	0	0	0	0
		After-sale Service	46	38	8	1	3	2	2	0	0	0	0	0	33	13	2	4	3	4	0	0	0	0	0
		Sub-Total	**119**	**87**	**32**	**6**	**14**	**9**	**3**	**0**	**0**	**0**	**0**	**0**	**79**	**40**	**4**	**17**	**14**	**5**	**0**	**0**	**0**	**0**	**0**
	Learning & Growth Analysis	Employee Engagement	69	53	16	2	6	2	4	1	1	0	0	0	52	17	3	5	2	3	2	2	0	0	0
		Social & Environmental Issue	19	14	5	0	0	0	0	4	0	1	0	0	14	5	0	0	0	0	5	0	0	0	0
		Sub-Total	**88**	**67**	**21**	**2**	**6**	**2**	**4**	**5**	**1**	**1**	**0**	**0**	**66**	**22**	**3**	**5**	**2**	**3**	**7**	**2**	**0**	**0**	**0**
	Total		**383**	**272**	**111**	**20**	**40**	**29**	**14**	**6**	**1**	**1**	**0**	**0**	**269**	**114**	**12**	**43**	**31**	**11**	**11**	**2**	**0**	**4**	**0**
		Percentage (%)		**71**	**29**	**27**				**2**					**70**	**30**	**25**				**4**				
Level 2 Manufacturing Perspective	Manufacturing Equipment	Organisational Support	47	28	19	8	2	8	1	0	0	0	0	0	31	16	3	4	8	1	0	0	0	0	0
		Planning	10	6	4	1	0	1	0	1	1	0	0	0	8	2	0	0	0	1	0	1	0	0	0
		Control	26	11	15	0	1	1	6	7	0	0	0	0	10	16	0	3	2	4	7	0	0	0	0
		Sub-Total	**83**	**45**	**38**	**9**	**3**	**10**	**7**	**8**	**1**	**0**	**0**	**0**	**49**	**34**	**3**	**7**	**10**	**6**	**7**	**1**	**0**	**0**	**0**
	Manufacturing Process	Organisational Support	48	36	12	3	2	5	0	0	1	1	0	0	41	7	1	0	4	0	0	1	1	0	0
		Planning	49	40	9	2	3	1	1	0	0	0	2	0	40	9	2	3	0	1	0	0	0	3	0
		Control	27	14	13	0	0	1	3	9	0	0	0	0	17	10	0	0	1	2	7	0	0	0	0
		Sub-Total	**124**	**90**	**34**	**5**	**5**	**7**	**4**	**9**	**1**	**1**	**2**	**0**	**98**	**26**	**3**	**3**	**5**	**3**	**7**	**1**	**1**	**3**	**0**
	Process Quality	Organisational Support	48	31	17	8	1	6	1	1	0	0	0	0	31	17	7	1	7	1	1	0	0	0	0
		Planning	21	15	6	0	2	0	0	3	1	0	0	0	13	8	0	4	0	0	3	1	0	0	0
		Control	12	6	6	0	0	1	1	4	0	0	0	0	3	9	0	0	2	2	5	0	0	0	0
		Sub-Total	**81**	**52**	**29**	**8**	**3**	**7**	**2**	**8**	**1**	**0**	**0**	**0**	**47**	**34**	**7**	**5**	**9**	**3**	**9**	**1**	**0**	**0**	**0**
	Total		**288**	**187**	**101**	**22**	**11**	**24**	**13**	**25**	**3**	**1**	**2**	**0**	**194**	**94**	**13**	**15**	**24**	**12**	**23**	**3**	**1**	**3**	**0**
		Percentage (%)		**65**	**35**	**24**				**11**					**67**	**33**	**22**				**10**				
Level 3 Maintenance Perspective - Maintenance Rules	Maintenance Policy	Planning	52	33	19	5	3	8	1	0	1	1	0	0	36	16	3	4	6	1	0	1	1	0	0
		Control	29	23	6	0	0	1	2	2	0	0	1	0	14	15	0	1	5	3	4	0	0	2	0
		Sub-Total	**81**	**56**	**25**	**5**	**3**	**9**	**3**	**2**	**1**	**1**	**1**	**0**	**50**	**31**	**3**	**5**	**11**	**4**	**4**	**1**	**1**	**2**	**0**
	Maintenance Organisation	Planning	17	11	6	0	0	2	1	1	0	1	0	1	10	7	0	1	1	1	0	0	0	0	4
		Control	11	1	10	0	0	1	3	6	0	0	0	0	3	8	0	1	2	1	4	0	0	0	0
		Sub-Total	**28**	**12**	**16**	**0**	**0**	**3**	**4**	**7**	**0**	**1**	**0**	**1**	**13**	**15**	**0**	**2**	**3**	**2**	**4**	**0**	**0**	**0**	**4**
	Maintenance Information &	Planning	20	13	7	3	4	0	0	0	0	0	0	0	15	5	2	3	0	0	0	0	0	0	0
		Control	7	1	6	0	0	1	2	3	0	0	0	0	2	5	0	0	3	1	1	0	0	0	0
		Sub-Total	**27**	**14**	**13**	**3**	**4**	**1**	**2**	**3**	**0**	**0**	**0**	**0**	**17**	**10**	**2**	**3**	**3**	**1**	**1**	**0**	**0**	**0**	**0**
	Total		**136**	**82**	**54**	**8**	**7**	**13**	**9**	**12**	**1**	**2**	**1**	**1**	**80**	**56**	**5**	**10**	**17**	**7**	**9**	**1**	**1**	**2**	**4**
		Percentage (%)		**60**	**40**	**27**				**13**					**59**	**41**	**29**				**13**				
Level 4 Maintenance Perspective - Maintenance Activities	Repairing Activity	Planning	10	6	4	0	1	3	0	0	0	0	0	0	3	7	0	3	4	0	0	0	0	0	0
		Control	13	5	8	0	0	1	1	6	0	0	0	0	5	8	0	0	0	1	7	0	0	0	0
		Sub-Total	**23**	**11**	**12**	**0**	**1**	**4**	**1**	**6**	**0**	**0**	**0**	**0**	**8**	**15**	**0**	**3**	**4**	**1**	**7**	**0**	**0**	**0**	**0**
	Retaining Activity	Planning	25	20	5	0	0	5	0	0	0	0	0	0	19	6	0	0	6	0	0	0	0	0	0
		Control	13	6	7	0	0	1	2	4	0	0	0	0	7	6	0	0	0	2	4	0	0	0	0
		Sub-Total	**38**	**26**	**12**	**0**	**0**	**6**	**2**	**4**	**0**	**0**	**0**	**0**	**26**	**12**	**0**	**0**	**6**	**2**	**4**	**0**	**0**	**0**	**0**
	Modification Activity	Planning	11	3	8	0	0	6	0	2	0	0	0	0	8	3	0	0	1	0	2	0	0	0	0
		Control	6	2	4	0	0	1	1	2	0	0	0	0	1	5	0	0	1	0	4	0	0	0	0
		Sub-Total	**17**	**5**	**12**	**0**	**0**	**7**	**1**	**4**	**0**	**0**	**0**	**0**	**9**	**8**	**0**	**0**	**2**	**0**	**6**	**0**	**0**	**0**	**0**
	Design Activity	Planning	11	4	7	0	0	4	0	3	0	0	0	0	10	1	0	0	0	0	1	0	0	0	0
		Control	6	0	6	0	0	2	1	3	0	0	0	0	1	5	0	0	0	1	4	0	0	0	0
		Sub-Total	**17**	**4**	**13**	**0**	**0**	**6**	**1**	**6**	**0**	**0**	**0**	**0**	**11**	**6**	**0**	**0**	**0**	**1**	**5**	**0**	**0**	**0**	**0**
	Total		**95**	**46**	**49**	**0**	**1**	**23**	**5**	**20**	**0**	**0**	**0**	**0**	**54**	**41**	**0**	**3**	**12**	**4**	**22**	**0**	**0**	**0**	**0**
		Percentage (%)		**48**	**52**	**31**				**21**					**57**	**43**	**20**				**23**				
Level 5 Maintenance Perspective - Maintenance Resources	Maintenance Personnel	Planning	25	21	4	0	2	1	0	1	0	0	0	0	21	4	0	1	2	0	1	0	0	0	0
		Control	16	6	10	0	0	3	2	5	0	0	0	0	11	5	0	2	1	0	2	0	0	0	0
		Sub-Total	**41**	**27**	**14**	**0**	**2**	**4**	**2**	**6**	**0**	**0**	**0**	**0**	**32**	**9**	**0**	**3**	**3**	**0**	**3**	**0**	**0**	**0**	**0**
	Maintenance Tools	Planning	7	4	3	0	1	2	0	0	0	0	0	0	5	2	0	1	1	0	0	0	0	0	0
		Control	10	4	6	0	0	0	2	4	0	0	0	0	3	7	0	1	1	2	3	0	0	0	0
		Sub-Total	**17**	**8**	**9**	**0**	**1**	**2**	**2**	**4**	**0**	**0**	**0**	**0**	**8**	**9**	**0**	**2**	**2**	**2**	**3**	**0**	**0**	**0**	**0**
	Maintenance Material	Planning	17	13	4	0	1	3	0	0	0	0	0	0	13	4	0	0	4	0	0	0	0	0	0
		Control	8	2	6	0	0	2	1	3	0	0	0	0	3	5	0	0	1	1	3	0	0	0	0
		Sub-Total	**25**	**15**	**10**	**0**	**1**	**5**	**1**	**3**	**0**	**0**	**0**	**0**	**16**	**9**	**0**	**0**	**5**	**1**	**3**	**0**	**0**	**0**	**0**
	Maintenance ICT	Planning	9	4	5	0	1	4	0	0	0	0	0	0	4	5	0	1	4	0	0	0	0	0	0
		Control	12	1	11	0	1	4	4	2	0	0	0	0	4	8	0	5	2	1	0	0	0	0	0
		Sub-Total	**21**	**5**	**16**	**0**	**2**	**8**	**4**	**2**	**0**	**0**	**0**	**0**	**8**	**13**	**0**	**6**	**6**	**1**	**0**	**0**	**0**	**0**	**0**
	Total		**104**	**55**	**49**	**0**	**6**	**19**	**9**	**15**	**0**	**0**	**0**	**0**	**64**	**40**	**0**	**11**	**16**	**4**	**9**	**0**	**0**	**0**	**0**
		Percentage (%)		**53**	**47**	**33**				**14**					**62**	**38**	**30**				**9**				
Grand Total			**1006**	**642**	**364**	**50**	**65**	**108**	**50**	**78**	**5**	**4**	**3**	**1**	**661**	**345**	**30**	**82**	**100**	**38**	**74**	**6**	**2**	**9**	**4**
Percentage (%)				**64**	**36**	**27**				**9**					**66**	**34**	**25**				**9**				

Table 8-45 Summary of AHP Analysis for KBIMSO validation

KBIMSO Level	Company X				Company Y			
	Module	PV	Sub-Module	PV	Module	PV	Sub-Module	PV
Level 1 Business Perspective	Company Statement Analysis	0.1274	Value Socialisation	0.3333	Company Statement Analysis	0.1078	Value Socialisation	0.3333
			Value Integration	**0.6667**			**Value Integration**	**0.6667**
	Financial Analysis	0.2357	Leverage Ratio	0.1676	Financial Analysis	0.2422	Leverage Ratio	0.1676
			Liquidity Ratio	0.1171			Liquidity Ratio	0.1171
			Efficiency Ratio	**0.4841**			**Efficiency Ratio**	**0.4841**
			Profitability Ratio	0.2311			Profitability Ratio	0.2311
	Customer Analysis	**0.3611**	**Customer Satisfaction**	**0.7500**	Customer Analysis	0.1867	**Customer Satisfaction**	**0.6667**
			Market Share	0.2500			Market Share	0.3333
	Internal Business Process Analysis	0.1801	**Product Development**	**0.6667**	**Internal Business Process Analysis**	**0.3200**	**Product Development**	**0.6667**
			After-sale Service	0.3333			After-sale Service	0.3333
	Learning & Growth Analysis	0.0957	**Employee Engagement**	**0.6667**	Learning & Growth Analysis	0.1433	**Employee Engagement**	**0.6667**
			Social & Environmental Issue	0.3333			Social & Environmental Issue	0.3333
Level 2 Manufacturing Perspective	**Manufacturing Equipment**	**0.4905**	**Organisational Support**	**0.4905**	Manufacturing Equipment	0.2973	**Organisational Support**	**0.3338**
			Planning	0.3119			Planning	0.1416
			Control	0.1976			Control	0.5247
	Manufacturing Process	0.1976	**Organisational Support**	**0.4905**	Manufacturing Process	0.1638	Organisational Support	0.1976
			Planning	0.1976			**Planning**	**0.4905**
			Control	0.3119			Control	0.3119
	Process Quality	0.3119	**Organisational Support**	**0.5889**	**Process Quality**	**0.5390**	**Organisational Support**	**0.4905**
			Planning	0.1593			Planning	0.1976
			Control	0.2519			Control	0.3119
Level 3 Maintenance Rules	Maintenance Policy	0.3119	**Planning**	**0.7500**	Maintenance Policy	0.3119	**Planning**	**0.6667**
			Control	0.2500			Control	0.3333
	Maintenance Organisation	0.1976	Planning	0.2500	Maintenance Organisation	0.1976	Planning	0.2500
			Control	**0.7500**			**Control**	**0.7500**
	Maintenance Inf. & Doc.	**0.4905**	**Planning**	**0.6667**	**Maintenance Inf. & Doc.**	**0.4905**	Planning	0.3333
			Control	0.3333			**Control**	**0.6667**
Level 4 Maintenance Activities	Repairing Activity	0.1872	**Planning**	**0.6667**	**Repairing Activity**	**0.4168**	**Planning**	**0.7500**
			Control	0.3333			Control	0.2500
	Retaining Activity	0.1080	Planning	0.3333	Retaining Activity	0.1928	Planning	0.3333
			Control	**0.6667**			**Control**	**0.6667**
	Modification Activity	0.2930	**Planning**	**0.6667**	Modification Activity	0.2695	Planning	0.2500
			Control	0.3333			**Control**	**0.7500**
	Design Activity	**0.4118**	Planning	0.3333	Design Activity	0.1209	Planning	0.2500
			Control	**0.6667**			**Control**	**0.7500**
Level 5 Maintenance Resources	Maintenance Personnel	0.1202	Planning	0.3333	Maintenance Personnel	0.1202	Planning	0.3333
			Control	**0.6667**			**Control**	**0.6667**
	Maintenance Tools	0.2596	**Planning**	**0.6667**	Maintenance Tools	0.2596	Planning	0.3333
			Control	0.3333			**Control**	**0.6667**
	Maintenance Material	0.1707	Planning	0.3333	Maintenance Material	0.1707	Planning	0.3333
			Control	**0.6667**			**Control**	**0.6667**
	Maintenance ICT	**0.4495**	Planning	0.3333	**Maintenance ICT**	**0.4495**	Planning	0.3333
			Control	**0.6667**			**Control**	**0.6667**

On the second level of *Strategic Stage*, *Level 2 – Manufacturing Perspective*, Company X and Y still show that they have similar critical problems in some areas, referring again to Table 8-44. The gap relationship could be explored in each module, down to sub-modules and KB rules. But the high intensity of relationship could be seen on *Organisational Support Sub-Module* within *Process Quality Module*, where both Company X and Y have same 17 BPs. Particularly on the most critical problem which is categorised as PC-1, Company X collect 8 PC-1 while Company Y collects 7 PC-1. Furthermore, although the percentage of BPs on Level 2 for each company are nearly the same, 35% (24% of more critical BPs vs. 11% of less critical BPs) on Company X and 33% (22% of more critical BPs vs. 10% of less critical BPs) on Company Y, the recommendations provided by KBIMSO for them are different. As shown in Table 8-45, Company X needs to focus on *Organisational Support Sub-Module* within *Manufacturing Equipment Module*, while Company X needs to focus on *Organisational Support Sub-Module* within *Process Quality Module*.

The third level of KBIMSO model, also the first level on *Maintenance Operations Stage*, is *Level 3 – Maintenance Rules*. Since this level is still discussing the commitment of organisation management to support its function, in extend to maintenance function, the trend of GAP analysis for both companies is still quite similar. Based on the absence of KB rules on all modules in this level, it can be concluded that the management style and corporate culture of the parent company strongly influence the subsidiaries, particularly on *Planning Sub-Module* under *Maintenance Policy Module*. Referring to Table 8-44, there are 19 BPs (17 BPs are concentrated on the first four PCs) identified on Company X while 16 BPs (14 BPs are concentrated on the first four PCs) identified on Company Y for this sub-module. But, the most problematic area for both companies that should be prioritised to tackle is identified in the last module of this level. As referred to Table 8-45, Company X has to deal with *Planning Sub-Module* while Company X has to deal with *Control Sub-Module,* both on *Maintenance Information and Documentation Module*.

Level 4 – Maintenance Activities, as the fourth level of KBIMSO as well as the second level on *Maintenance Operations Stage*, shows apparently the capability of each company in managing its maintenance function. Although these companies have a different concern to cope repairing activity, they have a similar perspective to deal with retaining activity. It could be seen from the consistency of both companies to carefully manage the planned maintenance, in context of preventive and predictive maintenance strategies. Referring to Table 8-44, there is no gap found in PC-1 or PC-2 categories on both companies. Meanwhile, there are 5 PC-3 and 6 PC-3 on *RetA Planning Sub-Module* for Company X and Y, respectively. Regarding the implementation of TPM on modification and design activities, both companies show a contradiction. Overall, Company X has to work more than Company Y to get the benefit of the implementation of TPM on its company. This is also reflected from the PV values in AHP analysis, as referred to Table 8-45, where the *Design Activity Module* (particularly on *Control Sub-Module*) on Company X requires more attention to rectify than others. On the other hand, Company Y needs to focus on *Repairing Activity Module* (particularly on *Planning Sub-Module*).

The last level in the KBIMSO model is Level 5 – Maintenance Resources Module. Similarly, Company X and Company Y face critical problems on Control Sub-Module from Maintenance Personnel Module, Maintenance Material Module, and Maintenance ICT Module, even though at different combination and number of KB rules, referring to Table 8-44. This condition represents that the performance of maintenance resources varies toward the benchmarks. The recommendation of improvement on this level through AHP analysis, as referred to Table 8-45, shows that both companies need to pay first attention to *Control Sub-Module* from *Maintenance ICT Module* before working on the other modules. The problems are dominantly caused by less supporting facilities to deploy CMMS effectively.

8.5 Verification and Validations of KBIMSO Based on the Published Case Study

Verification and validation in the KBIMSO model is one important step to ensure that this model can work to find the problem out and to recommend the solution. After being conducted on the industrial case study, verification and validation process of KBIMSO model is also conducted on the published case study, to confirm that the methodology used in the KBIMSO model works as good as the common procedure which has been known and used. By passing this, it can be confirmed that the result and analysis provided by KBIMSO model are valid and consistent.

8.5.1 Published Case Study of Honda: Financial Analysis Module

When validation of industrial data is addressed to examine all aspects of KBIMSO, the published case study deals only with quantitative information. The only one module of KBIMSO which could be verified and validated through published case study is *Financial Analysis Module*. By selecting a company from the same industrial background, a financial report from Honda Motor Co., Ltd. as one of the automotive industry leaders, is chosen in this study. The financial statements of Honda that has been fit into the KBIMSO format are presented in Table 8-46 (*Income Statement*) and Table 8-47 (*Balance Sheet*).

Table 8-46 Income Statement of Honda (An exchange rate of £1.00 = ¥ 137.00)

INCOME STATEMENT			
Currency in Millions of Pound Sterling as of:	**Mar 31, 2016**	**Mar 31, 2015**	**Mar 31, 2014**
Net sales	107,674.24	98,408.23	92,181.99
Cost of goods sold	82,718.24	75,407.18	70,004.07
Other expenses	15,362.50	12,419.58	10,974.73
Depreciation	4,822.73	4,563.72	4,292.93
Earnings before interest and taxes (EBIT)	**4,770.77**	**6,017.74**	**6,910.26**
Net interest expense	132.45	132.80	93.45
Taxes	1,672.20	1,789.34	1,956.15
Net Income	**2,966.12**	**4,095.61**	**4,860.66**

Table 8-47 Balance Sheet of Honda (An exchange rate of £1.00 = ¥ 137.00)

BALANCE SHEET			
Currency in Millions of Pound Sterling as of:	**Mar 31, 2016**	**Mar 31, 2015**	**Mar 31, 2014**
ASSETS			
Current assets			
Cash & equivalents	12,828.15	10,742.55	8,712.29
Marketable securities	752.08	676.70	744.67
Receivables	20,092.91	21,311.18	19,503.74
Inventories	9,586.07	10,936.58	9,742.88
Other current assets	2,300.11	2,290.20	1,801.21
Total current assets	**45,559.31**	**45,957.23**	**40,504.80**
Net fixed assets (after depreciation)	49,764.05	47,626.85	38,313.50
Intangible assets	6,021.45	5,544.05	4,888.93
Other assets	31,715.72	35,367.04	33,434.66
TOTAL ASSETS	**133,060.54**	**134,495.16**	**117,141.88**
LIABILITIES & SHAREHOLDERS' EQUITY			
Current liabilities			
Debt due to repayment	8,233.88	8,450.64	7,878.23
Accounts payable	27,906.18	26,777.99	23,981.56
Other current liabilities	3,789.51	3,465.19	2,824.88
Total current liabilities	**39,929.57**	**38,693.82**	**34,684.67**
Long-term liabilities	40,142.12	40,198.67	33,145.41
Other long-term liabilities	1,661.93	1,713.46	1,436.42
TOTAL LIABILITIES	**81,733.62**	**80,605.96**	**69,266.50**
Total shareholders' equity	51,326.92	53,889.20	47,875.39
TOTAL LIABILITIES & SHAREHOLDERS' EQUITY	**133,060.54**	**134,495.16**	**117,141.88**

Similar to the process done on the industrial data, the financial data from published case study is put into KBIMSO model application. By using internal KB rules, the financial ratios and the trends are calculated, as the result shown in Table 8-48.

Table 8-48 KBIMSO Financial Analysis for Honda

FINANCIAL ANALYSIS						
As of:	**Mar 31, 2016**		**Mar 31, 2015**		**Mar 31, 2014**	
Financial Ratio	**Value**	**(Category)**	**Value**	**(Category)**	**Value**	**(Category)**
Leverage Ratio						
Debt Ratio (DR)	0.61	(PC-2)	0.60	(PC-3)	0.59	(PC-3)
DR Trend (Category)	increased (PC-2)			increased (PC-3)		
Debt Equity Ratio (DER)	1.59	(PC-2)	1.50	(PC-3)	1.45	(PC-3)
DER Trend (Category)	increased (PC-2)			increased (PC-3)		
Times Interest Earned Ratio (TIER)	36.02	(GP)	45.31	(GP)	73.94	(GP)
TIER Trend (Category)	decreased (PC-2)			decreased (PC-3)		
Liquidity Ratio						
Current Ratio (CurR)	1.14	(GP)	1.19	(GP)	1.17	(GP)
CurR Trend (Category)	decreased (PC-2)			increased (GP)		
Cash Ratio (CasR)	0.34	(PC-2)	0.30	(PC-3)	0.27	(PC-3)
CasR Trend (Category)	increased (GP)			increased (GP)		
Quick Ratio (QR)	0.84	(PC-2)	0.85	(PC-3)	0.83	(PC-3)
QR Trend (Category)	decreased (PC-2)			increased (GP)		
Efficiency Ratio						
Asset Turnover Ratio (ATR)	0.80	(PC-2)	0.78	(PC-3)		
ATR Trend (Category)	increased (GP)					
Inventory Turnover Ratio (ITR)	8.06	(GP)	7.29	(GP)		
ITR Trend (Category)	increased (GP)					
Profitability Ratio						
Net Profit Margin Ratio (NPMR)	0.03	(GP)	0.04	(GP)	0.05	(GP)
NPMR Trend (Category)	decreased (PC-2)			decreased (PC-3)		
Return on Assets Ratio (RoA)	0.02	(GP)	0.03	(GP)		
RoA Trend (Category)	decreased (PC-2)					
Return on Equity Ratio (RoE)	0.06	(GP)	0.08	(GP)		
RoE Trend (Category)	decreased (PC-2)					
Return on Investment Ratio (RoI)	0.02	(GP)	0.03	(GP)	0.04	(GP)
RoI Trend (Category)	decreased (PC-2)			decreased (PC-3)		

Referring to Table 8-48, Honda has quite bad records on *Leverage Ratio* where most of KB rules are indicated as BPs, on both ratios' values and trends. Since *Leverage Ratio* indicates how much financial leverage the company has taken on, Honda expects to have low *Debt Ratio* and *Debt Equity Ratio* but high *Times Interest Earned Ratio*. After calculating the relevant variables, Honda has *Debt Ratio* and *Debt Equity Ratio* values higher than 0.5 in three consecutive years, which are categorised as BPs. Meanwhile, *Times Interest Earned Ratio* values for the last three consecutive years are high and categorised as GPs. Unfortunately, the trends of all ratios within *Leverage Ratio* show unexpected performance which are indicated as BPs.

On *Liquidity Ratio*, which shows Honda's ability to fulfil short-term liabilities, only *Current Ratio* values are indicated as GPs. This means that Honda has adequate current assets to pay its short-term liabilities. Meanwhile, the trend of *Current*

Ratio is fluctuating and decreasing (BPs). In contrast, values of *Cash Ratio* and *Quick Ratio* in three consecutive years are categorised as BPs, which mean that Honda has less cash than expected to pay its short-term liabilities. Although being classified are BPs, these values are increasing which indicate a good trend (classified as GPs).

To assess how effective the capital is employed in Honda, *Efficiency Ratio* is examined with two ratios; *Asset Turnover Ratio* and *Inventory Turnover Ratio*. Although in three consecutive years, Honda experiences BPs on *Asset Turnover Ratio* values, these values improve and show a good trend (GPs). Meanwhile, *Inventory Turnover Ratio* shows good values and good trend where all KB rules examined on this ratio are categorised as GPs.

The last ratio counted is *Profitability Ratio*, which tells how Honda can earn profits and return its investment. From four ratios measured, all of them indicate that Honda is healthy enough to earn a profit, which is indicated by having good values (classified as GPs). However, the trends of all ratios are decreasing (classified as BPs) which means that Honda faces degradation of *Net Income*. *Net Sales* is slightly increased yet followed by a sharp increase in *Cost of Goods Sold* and *Other Expenses*, referring to Table 8-46. In fact, the number of unit sales is decreasing in many marketplaces (countries) as the impact of the global economic condition.

8.5.2 Reflection on the Published Case Study Analysis

Comparing to the released annual report of Honda, year ended March 31, 2016 (Honda Motor Co. Ltd., 2016), the analysis provided by KBIMSO model show the similarity and consistency result. Confirming to Honda annual report, the overall financial performance concluded by KBIMSO on three consecutive years is low and decreasing. Although having less impressive financial achievement in 2016, Honda can still be confident with its business in the future since this low performance is caused by external reason. In fact, this financial condition evenly happened on different companies within this industry.

By verifying and validating *Financial Analysis Module* with the published case study, it can be confirmed that the KBIMSO model works as expected and provides a similar result as indicated in the published financial report. Since the

KB rules are attached with GAP analysis, KBIMSO can also assist the company to identify the critical problem and propose recommendation for the improvement priority. Hence, the KBIMSO model proves that it is capable to support decision making.

8.6 Summary

This chapter demonstrates verification and validation steps for the KBIMSO model. The process is intended to prove that the KBIMSO model can work consistently and accurately to identify the problem and to recommend the solution. There are two industrial case studies and one published case study involved in the process. For the industrial case study, two automotive companies from Indonesia are selected, so-called Company X and Company Y. By considering the request from those companies, their names are hidden. For the published case study, the financial report of Honda Motor is selected from the online released annual report, which is taken from its official website. The verification and validation process on all levels of the KBIMSO model for Company X are detailed in this chapter while detail results for Company Y are given in Appendix B. However, the summary and recommendations for both companies are explained within this chapter.

The whole process of verification and validation of the KBIMSO model is started by identifying business profile of the company. This step is followed by investigating company environment to understand company current condition and ensure that the company has required capabilities to implement KBIMSO. The verification and validation are started from *Level 1* to *Level 5* of the KBIMSO model. The user from each company gives the response regarding KB rules on each module through KBIMSO application. The response is then tabulated to identify the composition of Good Points and Bad Points (with the PC levels) as part of GAP analysis. Priority of improvement for sub-modules (within a certain module) and modules (within a certain level) are then proposed by using AHP analysis which is integrated into the KBIMSO.

As the result of verification and validation, KBIMSO recommends of which sub-module and module should be prioritised on each level to get improvement. In *Level 1 – Business Perspective*, Company X has to prioritise on *Customer*

Satisfaction Sub-Module from *Customer Analysis Module*, while Company Y has to prioritise on *Product Development Sub-Module* from *Internal Business Process Analysis Module*. In *Level 2 – Manufacturing Perspective*, Company X and Company Y similarly have a critical problem with Org*anisational Support Sub-Module*. The different is Company X has to deal with *Manufacturing Equipment Module* whilst Company Y has to deal with *Process Quality Module*. In *Level 3 – Maintenance Rules*, both companies have similar priority to solve the problem on *Maintenance Information and Documentation Module*, but on different aspects. When Company X has to focus on *Planning Sub-Module*, Company Y has to focus on *Control Sub-Module*. In *Level 4 – Maintenance Activities*, Company X needs to pay first attention to *Control Sub-Module* from *Design Activity Module*, whereas Company Y needs to pay first attention to *Planning Sub-Module* from *Repairing Activity Module*. On the last level, *Level 5 – Maintenance Resources*, Company X and Company Y similarly have to take priority of improvement plan on *Control Sub-Module* of *Maintenance ICT Module*.

After getting the result of maintenance performance and proposing a recommendation to support maintenance decision making for both Company X and Y, the gap relationship between these companies is examined. The gap relationship analysis can benefit both companies to get the lessons each other about how to run better maintenance as part of knowledge sharing for continuous improvement. On the other hand, this analysis could assist to understand automotive industry management style from business level to maintenance function as well as the characteristic of corporate culture in certain place (in this case: Indonesia).

Particularly on *Financial Analysis Module* in *Level 1 – Business Perspective*, the input is taken from the released financial statements on the company annual report. Since the financial statements are the standardised documents to figure out the financial analysis, it can also be validated through the published case study. The result of financial analysis calculated by the KBIMSO application is then compared with financial analysis explained by the company in its annual report. The comparison proves that KBIMSO works as expected and provides a similar result.

By the end of this chapter, it can be confirmed that the KBIMSO model as a novel approach for integrated maintenance strategy and operations works successfully to support maintenance decision making by assisting the company to set the priority of improvement to increase maintenance performance.

CHAPTER 9

Conclusion and Recommendations

9.1 Introduction

This chapter summarises the thesis finding on the importance of integration of maintenance strategy and operations through the implementation of the KBIMSO. In KBIMSO, maintenance is not only considered as a segmented function which purely works to maintain equipment availability and reliability, but it is considered in a wide perspective as a business driver to support business competitiveness. Therefore, the integration of maintenance with manufacturing and business perspectives is very important to support maintenance performance to reach the business goal. The developed KBIMSO model consists of *Level 1 – Business Perspective*, *Level 2 – Manufacturing Perspective*, *Level 3 – Maintenance Rules*, *Level 4 – Maintenance Activities*, and *Level 5 – Maintenance Resources*. These five levels are then expanded into modules and sub-modules which contain KB rules to investigate all requirements contributed to maintenance decision making.

9.2 Research Achievement

The current researches on maintenance strategy are dominated by a selection of the best-fit maintenance policy based on different criteria. The results are addressed to choose whether preventive maintenance, predictive maintenance, condition-based maintenance or others that fit with a particular company. In fact, maintenance strategy does not only consist of that decision, but also about maintenance personnel and skill improvement, maintenance organisation, maintenance inventory, and other factors. Meanwhile so far, the different methods used require tedious and complicated calculations to be implemented practically.

The development of the hybrid KB System/GAP/AHP methodology is new and novel in the area of maintenance, particularly in developing an integrated maintenance strategy and operations linked to manufacturing and business perspectives. Previously, the hybrid KB-GAP-AHP system has been applied in the area of performance measurement system (Wibisono, 2003), supply chain management (Udin, 2004), lean manufacturing (Nawawi, 2009), low volume automotive manufacturing (Mohamed, 2012), and sustainable building (Dairi, 2017).

This research aims to develop a KB system to facilitate the integration of maintenance strategy and operations with business and manufacturing perspectives to support maintenance decision making within automotive industry environment. Although this model could be applied in different type of industry, this research is focussed in the automotive industry environment. The highly automated equipment in the automotive manufacturing system requires the bigger support of maintenance to produce high-quality vehicles which in turn significantly contributes to sustain company competitiveness.

On its development, the KB system is combined with GAP analysis and AHP analysis which comes out as the hybrid KB system called Knowledge-Based System for Integrated Maintenance Strategy and Operations (KBIMSO). The KB system plays the role of generating KB rules in the form of IF…THEN…statements which connect data and information to create knowledge. The KB rules identify related indicators from business, manufacturing and maintenance perspective as pre-requisites to achieve the benchmarks. Meanwhile, the PC rating within GAP analysis supports each KB rule to rate the importance of such KB rule to the maintenance system performance. Finally, the AHP analysis is deployed by linking and comparing the elements and then weighting them proportionally to set the improvement priority.

Having the hybrid KBIMSO model which integrates three methodologies, the contribution of this research could be summarised as the following:

- This KBIMSO model could help the company to review its existing maintenance system performance related to business and manufacturing perspective, and find the gap between existing implementation of maintenance strategy and operations with benchmarks.
- This KBIMSO model could produce reasonable recommendations for maintenance decisions. The recommendations are addressed to business, manufacturing, and maintenance perspective by highlighting the critical

issues on each perspective that should be rectified to improve maintenance performance.

- The KBIMSO is considered to indicate the roadmap from the current state to the benchmark goals for the maintenance system.

The objectives of the research outlined in Chapter 1 (Introduction) have been successfully achieved through the development, implementation, verification and validation of the KBIMSO model. Chapter 1 of the research has proceeded from a background of the growth of maintenance function in-line with the growth of technology, which led to the shift of maintenance perspective from a 'fire-fighter' function to a business driver. Furthermore, this discussion recognised the relation of maintenance function with manufacturing function and business strategy, which then was used to formulate the research aim and objectives. The research methodology was then developed based on this preliminary study. The research was directed to develop an Integrated Maintenance Strategy and Operations (IMSO) by using a hybrid KB system. The hybrid KB system on this research is the combination of KB system with GAP and AHP analysis. This research aims to develop a KBIMSO model to support maintenance decision linked with manufacturing and business perspectives.

To extend the discussion in Chapter 1, literature review of some related subjects were carried out. In Chapter 2, maintenance was discussed from the very basic maintenance terminology to practical maintenance functions and policies. It encompassed the definition of maintenance, the function of maintenance, maintenance policies, the relevance of equipment characteristics and manufacturing process condition, and some other maintenance concepts. Following this literature review, the classification of maintenance policies was re-defined by including aggressive maintenance as another maintenance policy. Some maintenance concepts were also discussed to explain typical maintenance policy and maintenance activity adopted to improve maintenance performance.

In Chapter 3, literature review focused on maintenance strategy and operations and its relation to manufacturing and business perspective. This chapter explained the interrelation of maintenance with other functions horizontally, and interrelation of maintenance with business structure and strategy vertically to develop maintenance strategy. Therefore, the essence of business strategy was also generally discussed. At the end of the chapter, the discussion was shrunk to a mutual interrelation of business, manufacturing, and maintenance.

Different from the above chapters which were emphasised on discussing the background of the research, Chapter 4 was intended to conduct the literature review on the methodology used to support the research. Adopting Knowledge Management philosophy, this research highlighted the importance of retaining knowledge within the organisation regardless the existence of the experts whom the knowledge belongs to. Furthermore, the use of Artificial Intelligence was introduced. There are at least five branches of AI explained in this chapter, which are ANN, CBR, GA, FS, and ES/KB. The latter was selected as the supporting tool for this research. Since this research was also supported by GAP and AHP methodologies to proportionally handle multi-criteria decision making, these two methods were discussed at the end of the chapter. By this point, the research objectives (i) to (iii) had been achieved.

The second part of the research is methodology, which was discussed in Chapter 5, 6, and 7. In Chapter 5, the relationship of maintenance with manufacturing and business, together with methodologies and implementation of the research were structured into a KBIMSO framework. There were four stages included in the KBIMSO framework. The first stage was *Strategic Stage* which encompassed business and manufacturing perspectives. The *Business Perspective* was represented through the Balanced Scorecard (BSC) as strategic performance measurement tool to communicate strategic Key Performance Indicators (KPIs) across the organisation. These strategic KPIs included the *Financial*, *Customer*, *Internal Business Process*, and *Learning and Growth Analysis*. *Company Statement Analysis* was added to incorporate those aspects into the KBIMSO framework. The *Manufacturing Perspective* contained *Manufacturing Equipment*, *Manufacturing Process*, and *Process Quality* aspects. The second stage was *Operation Design Stage* which considered strategic elements of the maintenance function. It included *Maintenance Rules, Maintenance Activities*, and *Maintenance Resources*. The methodology used to support the research was included in the third stage, *KB Model Design Stage*. This stage revealed the contribution of KB system, GAP analysis, and AHP analysis to generate a recommendation. The fourth stage was the *Implementation*, where alternatives of implementation were presented to guide the company in preparing and executing improvement plan based on the KBIMSO recommendation. One alternative of the KBIMSO was intended for problem resolution. It adopted *Define-Measure-Analyse-Improve-Control (DMAIC)* method of Six Sigma to overcome existing problems identified. In contrast, the second alternative was intended for problem prevention. This can be done through *Define-Characterise-Organise-Verify (DCOV)* method of Six Sigma to avoid potential problems identified. The KBIMSO framework corresponded to the research objectives (iv).

In Chapter 6 and 7, the important aspects on KBIMSO framework were descended, respectively, into six important levels to develop a KBIMSO model, which are *Level 0 – Company Environment*, *Level 1 – Business Perspective*, *Level 2 – Manufacturing Perspective*, *Level 3 – Maintenance Rules*, *Level 4 – Maintenance Activities*, and *Level 5 – Maintenance Resources*. The first three modules were discussed in Chapter 6 while the last three modules were discussed in Chapter 7. In the KBIMSO model, each level was expanded into modules and sub-modules. The relevant KB rules were then generated on each sub-module with the PC attached to each KB rule (except Level 0) to accommodate GAP analysis. By using a software from AM Manager, a KBIMSO application was developed based on the structure of the KBIMSO model. Such application was facilitated with the user interface, explanation facility, and inference engine in order to provide improvement recommendation to support maintenance decision making. The recommendations were generated from GAP and AHP analysis which proportionally weight the PC on each KB rules and then compared them in a pair-wise manner to identify the critical problem as the priority of improvement. This recommendation comes out on each level by identifying which module and sub-module should be prioritised to improve maintenance performance. The works within these two chapters were addressed to achieve the research objectives (v) and (vi).

The last main part of the research is Results and Discussions in Chapter 8 and 9. Verification and validation of the KBIMSO model in Chapter 8 were intended to achieve the research objective (vii). It was conducted in two automotive companies and a published case study. The integration of hybrid KB system/GAP/AHP methodology was demonstrated at this stage to confirm that the KBIMSO model can work to recommend improvement priority for maintenance decision making. The combination of GAP analysis and AHP analysis within a KB system proved that the KBIMSO can provide a valid and consistent result. The outcome of this research was capable to support maintenance decision making during the review and improvement plan of the maintenance strategy and operations. Moreover, the proposed approach aligned maintenance function, manufacturing function, and business strategic level.

Finally in Chapter 9, the research achievements were concluded by corresponding to the research objectives. Furthermore, the advantages and limitations of the developed KBIMSO model were highlighted. These results were used to recommend the future works to achieve the research objective (viii).

9.3 Advantages of the KBIMSO model

The advantage of the KBIMSO has been identified during the development, verification and validation process as the following:

- The KBIMSO is developed by considering the integration of maintenance with manufacturing and business level. Therefore the KB rules cater for a complex integration of financial, customer, business process and learning and growth aspects within business perspective. Moreover, on the functional level, relevant aspects of manufacturing and maintenance are highlighted to describe a relationship among them which influence maintenance performance. This pattern is adaptable to maintenance function on different companies to get the same benefits. The KBIMSO framework as the early step of development is easily adjusted to fit with other companies' needs.
- Following the advantage from the previous point, the other functions in the company which plan to adopt the KBIMSO approach can utilise the information in the KBIMSO storage which relates to their needs and objectives. For example, the information related to business performance indicators could be reused by other functions in order to develop a decision making supporting tool which integrates with business perspective.
- The availability of explanation facility in the KBIMSO is also useful for knowledge sharing. Storing knowledge within the KBIMSO enables such

knowledge to be retrieved by other members of organisation even though the old members already leave the company. It gives the understanding of how a certain KB rule is generated and the reason to attach a particular PC rating on it. It could also be useful as a source of information to enable knowledge creation.

- As part of Artificial Intelligence, the use of KB rules in the KBIMSO to make an inference is useful to explain the evidence and reasoning of performance assessment. Moreover, the KBIMSO then integrates GAP analysis to rate the PC for each KB rules and AHP analysis to weight them and set up the improvement priority. This hybrid methodology helps the company to clearly identify the problems and get a valid and rational recommendation to set up the priority of where the improvement should be concentrated at the first time.
- The KBIMSO application is developed by using dedicated KB system software in modular basis which is integrated as a whole system. Thus the KBIMSO is easy and flexible to alter and modify the KB rules or PC rating to accommodate new knowledge acquisition and dynamic changes in the business environment. The impact of the changes could influence the recommendation of prioritised modules and sub-modules.
- In order to set the KB rules on its system, the KBIMSO refers to the benchmark practices. It could help the company to assess its performance target through the implementation of KBIMSO.

9.4 Limitations of the Research

Verification and validation of the developed KBIMSO model have proved that this approach can provide a valid, consistent, and rational recommendation to support maintenance decision making. In spite of its reliability, the KBIMSO model is still positioned at the early prototype stage. Thus there are some limitations to deal with, as the following:

- The KBIMSO framework is general and applicable for different backgrounds, while the KBIMSO model is validated in automotive industry. However, it could be irrelevant to be implemented on some other types of industry. To get the benefit of this hybrid KB system, some modifications on framework structure, main aspects, and KB rules are required.

- The comprehensiveness of generated KB rules and explanations depends on the intensity of knowledge acquisition, the know-how of experts whom the rules and explanations are discussed with, and access to knowledge resources. Therefore, the KBIMSO should be considered as a dynamic model that will be grown in line with the new knowledge acquisition and benchmark standard.
- To avoid uncertainty on KB rules interpretation, the KBIMSO is incorporated with explanation facility instead of fuzzy logic or Bayesian logic. Therefore, it is crucial for a knowledge engineer to have an intense discussion with human experts in the area of maintenance, manufacturing, and business to ensure that the KB rules and the explanation statements are using common terms for the users to understand.
- The KBIMSO application is developed by using AM software which has a limitation on memory capacity, less flexibility when inputting and altering model logic and limitation on interface resolution. Moreover, the integration of GAP and AHP methods to inference engine of KBIMSO increases the number of logic statements (syntaxes) significantly. These limitations influence the effectiveness of the KBIMSO application during execution.
- The KBIMSO application works as a “black box” where the information has entered the system, then the output is presented at the end without showing the process of reaching the result (Mosqueira-Rey et al., 2008). Although the mechanism of how the KBIMSO works is presented at different menu/page of the application, it does not give the real experience of how the KBIMSO comes with the recommendation. Therefore, it is necessary to socialise the process inside the KBIMSO to the top management as decision maker so they are confident to actualise the KBIMSO recommendation into an improvement plan.

9.5 Recommendations for Future Work

After completing the research of the KBMSO development and reflecting throughout the whole process, there are still some areas of further improvements could be recommended, as the following:

- The KBIMSO model is validated in the automotive companies, with a particular area of Body Part Manufacturing. The implementation of such approach in different shop floors is challenging by modifying KB rules in manufacturing perspective related to equipment, process and expected process quality which also influence the role of maintenance and expected maintenance performance.

- Not only with business level and manufacturing function, maintenance decisions also correlate with quality function and other related functions which potentially enable the development of the KBIMSO model in a wider scope.
- According to the flexibility of KBIMSO framework to be converted to different areas, as well as the availability of some general KB rules could be used, it will be potential for other functions to adopt this approach to support their decision making. Moreover, the integration and implementation of this approach all together on the entire organisation could ease information access across functions and enable the integrated business strategy to reach a business goal.
- There are over 2000 KB rules have been generated to develop the KBIMSO model. This number could increase to cover the integration of the entire organisation as indicated on the previous point. Since there is no such a perfect system but a better one, the increase of knowledge acquisition will add KBIMSO aspects, their KB rules, and explanations.
- The explanation facility is used in the KBIMSO to reduce subjectivity and to avoid the ambiguity of KB rules statement. The collaboration of this hybrid method with fuzzy logic could be attempted to compare the effectiveness and validity of each methodology.
- Since the KBIMSO is validated in Indonesia, there is a big opportunity to learn the result when it is implemented in different countries which have different corporate culture and environments.
- The KBIMSO model is a prototype model which has not reached a real implementation. Therefore, the *Implementation Stage* mentioned in the KBIMSO framework cannot be discussed yet. By implementing the recommendation proposed by the KBIMSO model based on either problem resolution (DMAIC) or problem prevention (DCOV) of Six Sigma, the KBIMSO effectiveness could be reviewed.

9.6 Final Remarks

This chapter apparently indicates that this research has reached its end. The aim of research stated in Chapter 1 has been achieved. Meanwhile, the milestones of the research which were represented by research objectives have been stepped in and achieved. The summary of each chapter and the achievement of each research objective have been highlighted on. By that point, the advantages, limitation of the research, and potential future work have been revealed.

The researcher, in this case, was acting as knowledge engineer who initially works to formulate the suitable framework for IMSO. The IMSO model is the approach developed by integrating some methods, so-called KBIMSO, a hybrid tool of KB system/GAP/AHP to propose recommendation for IMSO. With discussion with academic experts and practitioners, the formulations of KB rules, the PC attached to each rule, and explanation to support the rules have carefully been developed.

Within the KBIMSO model, the KB rules were generated, structured, and set into an application to support the KBIMSO in populating the input, process it, and producing the valid and consistent recommendation. Additionally, the KBIMSO model and application enabled implementation of Knowledge Management aspects of knowledge acquisition, knowledge storing, knowledge sharing, knowledge retrieving, and knowledge creating.

The KBIMSO framework was developed as the preliminary step to provide the backbone of the KBIMSO model. It gave a general overview of what aspects included, the methodology used, the recommendation structure, and the implementation alternatives. The KBIMSO model was then built from six levels, eleven modules, and forty-three sub-modules. It began with Level 0 that investigated the company environment. Then, Level 1 to Level 5 contained the main aspects to integrate maintenance decision making with business and manufacturing perspectives. By generating KB rules on each module and sub-module, and embedding GAP analysis and AHP analysis into the KB system, the KBIMSO model was confirmed as a powerful approach to assess integrated maintenance performance and to recommend aspects prioritised for improvement.

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APPENDIX A

THE AHP CALCULATION PROCEDURE

This appendix demonstrates the procedure taken for AHP calculation. The pair-wise comparison for *Level 5 – Maintenance Resources* is presented below to illustrate the process. The AHP calculation in KBIMSO is taken after conducting a GAP analysis, which is tabulating the gaps identified in a certain maintenance system based on categorised PCs. By weighing those PCs and assigning them to the Intensity of Importance based on AHP methodology, the AHP matrices could be formed. The formulated matrix of AHP through pair-wise comparison for Level 5 is shown in Table A-1.

Table A-1 Matrix of AHP Pair-Wise Comparisons

Modules	Personnel	Tools	Material	ICT
Personnel	1	1/2	1/2	1/3
Tools	2	1	2	1/2
Material	2	1/2	1	1/3
ICT	3	2	3	1

To figure out the consistency of this matrix, it should be synthesised and normalised. The synthesising of the matrix is achieved by adding up the values vertically on each column to get the total value per column, as shown in Table A-2.

Table A-2 Synthesising the Matrix of AHP Pairwise Comparisons

Modules	Personnel	Tools	Material	ICT
Personnel	1	**1/2 = 0.5**	**1/2 = 0.5**	**1/3 = 0.333**
Tools	**2**	1	**2**	**1/2 = 0.5**
Material	**2**	**1/2 = 0.5**	1	**1/3 = 0.333**
ICT	**3**	**2**	**3**	1
$\sum a_{ij} =$	**8.000**	**4.000**	**6.500**	**2.167**

Having the matrix synthesised, the next step is normalising the matrix by dividing each value on one column with the total value of that column, as shown in Table A-3.

Table A-3 Normalising the Matrix of AHP Pairwise Comparisons

Modules	Personnel	Tools	Material	ICT
Personnel	1/8	0.5/4	0.5/6.5	0.333/2.167
Tools	2/8	1/4	2/6.5	0.5/2.167
Material	2/8	0.5/4	1/6.5	0.333/2.167
ICT	3/8	2/4	3/6.5	1/2.167

The result obtained from the normalised matrix is used to calculate the Priority Vector (PV) of each module. The PV value equals the average of all values in one row. The PV value of each module under Level 5 is presented in Table A-4.

Table A-4 Priority Vectors of the AHP Matrix

Modules	Personnel	Tools	Material	ICT	Total	Average (Priority Vector)
Personnel	0.125	0.125	0.077	0.154	0.481	0.120
Tools	0.250	0.250	0.308	0.231	1.038	0.260
Material	0.250	0.125	0.154	0.154	0.683	0.171
ICT	0.375	0.500	0.462	0.462	1.798	0.450

Before taking the highest PV value as the recommended module to get the first improvement within Level 5, one preliminary requirement should be fulfilled, which is proving the consistency of PV, called Consistency Ratio (CR). The CR value that is bigger than 0.10 means that there is more than 10% possibility that the elements have not been compared properly. This condition requires the decision maker to review the comparison again until the CR value less or equal to 0.10.

The early step to measure CR is started by multiplying each value in a certain column of the matrix with its PV value, as shown in Table A-5.

Table A-5 Multiplication of Entries with PV

Modules	Personnel	Tools	Material	ICT
Personnel	1 x 0.120	0.5 x 0.260	0.5 x 0.171	0.333 x 0.450
Tools	2 x 0.120	1 x 0.260	2 x 0.171	0.5 x 0.450
Material	2 x 0.120	0.5 x 0.260	1 x 0.171	0.333 x 0.450
ICT	3 x 0.120	2 x 0.260	3 x 0.171	1 x 0.450

After that, the values in one row are added-up to get the total value of the specified row. This result is then divided by corresponding PV value to get New Vector (NV) value, as tabulated in Table A-6.

Table A-6 Calculation of NV Values

Modules	Personnel	Tools	Material	ICT	Total	NV = Total/PV
Personnel	0.120	0.130	0.085	0.150	0.485	4.037
Tools	0.240	0.260	0.341	0.225	1.066	4.106
Material	0.240	0.130	0.171	0.150	0.691	4.047
ICT	0.361	0.519	0.512	0.450	1.841	4.096

Referring back to obtain CR, the CR of each matrix is measured by the equation below:

$$CR = \frac{CI}{RI}$$

where CI is consistency index and RI is a known random consistency index.

The value of CI can be found by calculating λ_{max} in the equation below:

$$CI = \frac{\lambda_{max} - n}{n-1}$$

where λ_{max} is the largest eigen factor in the matrix (Aguilar-Lasserrea et al., 2009) and n is matrix size. λ_{max} is obtained through the average of NV values:

$$\lambda_{max} = \frac{4.037+4.106+4.047+4.096}{4} = 4.072$$

while matrix size is 4. Having λ_{max} is obtained; CI is calculated by using the equation below:

$$CI = \frac{4.072-4}{4-1} = 0.024 = 2.4\%$$

The value of RI has been defined from a large number of simulation which runs and varies depending upon the order matrix (Ilangkumaran and Kumanan, 2009), as shown in Table A-7.

Table A-7 Average random consistency index (Saaty and Vargas, 2001)

N	1	2	3	4	5	6	7	8
RI	0	0	0.52	0.89	1.11	1.25	1.35	1.41

According to Table A-7, RI for a matrix size of 4 is 0.89. By knowing CI and RI, CR could be counted by as the following:

$$CR = \frac{0.024}{0.89} = 2.68\%$$

Since CR is less than 10%, it can be justified that the judgement made for Level 5 of KBIMSO is consistent. Thus, the highest PV value of *Maintenance ICT Module* is confirmed as KBIMSO recommendation for Level 5.

APPENDIX B

VERIFICATION AND VALIDATION RESULT OF INDUSTRIAL CASE STUDY

Table B-1 Availability of Company Statements of Company Y

Company Statements	Avalailability
Vision Statement	Available
Mission Statement	Available
Objective Statement	Available

Table B-2 Company Current State of Company Y

User Profile	
Position	Maintenance Manager
Management Level	Middle Level Management
Department	Maintenance Department
Company Profile	
Position in Automotive Industry	Original Equipment Manufacturer (OEM)
Products	Four-wheeler automotive cars
Number of Employees	> 2500
Annual Turnover	> £ 50 million
Age of Organisation	38 years (established in 1978)
Business Competitiveness	
Number of Suppliers	> 150
Number of National Competitors	> 5
Market Place:	
National	Yes
Regional	Yes
Global	Yes
Maintenance-focused Policy	
Corrective Maintenance	Yes
Preventive Maintenance	Yes
Predictive Maintenance	Yes
Aggressive Maintenance	Yes
Corporate Sustainability	
Social Programmes	Yes
Environmental Programmes	Yes

Table B-3 Summary of GAP Analysis for Level 1 – Business Perspective for Company Y

KBIMSO Level	Module	Sub-Module	Number of KB Rules	GAP Analysis for Company Y: GP	BP	Problem Category (PC): 1	2	3	4	5	6	7	8	9
Level 1 Business Perspective	Company Statement Analysis	Value Socialisation	21	17	4	0	0	2	2	0	0	0	0	0
		Value Integration	14	12	2	0	2	0	0	0	0	0	0	0
		Sub-Total	**35**	**29**	**6**	**0**	**2**	**2**	**2**	**0**	**0**	**0**	**0**	**0**
	Financial Analysis	Leverage Ratio	15	10	5	0	1	4	0	0	0	0	0	0
		Liquidity Ratio	15	11	4	0	1	3	0	0	0	0	0	0
		Efficiency Ratio	6	2	4	0	3	1	0	0	0	0	0	0
		Profitability Ratio	16	10	6	0	4	2	0	0	0	0	0	0
		Sub-Total	**52**	**33**	**19**	**0**	**9**	**10**	**0**	**0**	**0**	**0**	**0**	**0**
	Customer Analysis	Customer Satisfaction	70	52	18	5	9	3	1	0	0	0	0	0
		Market Share	19	10	9	0	1	0	0	4	0	0	4	0
		Sub-Total	**89**	**62**	**27**	**5**	**10**	**3**	**1**	**4**	**0**	**0**	**4**	**0**
	Internal Business Process Analysis	Product Development	73	46	27	2	13	11	1	0	0	0	0	0
		After-sale Service	46	33	13	2	4	3	4	0	0	0	0	0
		Sub-Total	**119**	**79**	**40**	**4**	**17**	**14**	**5**	**0**	**0**	**0**	**0**	**0**
	Learning & Growth Analysis	Employee Engagement	69	52	17	3	5	2	3	2	2	0	0	0
		Social & Environmental Issue	19	14	5	0	0	0	0	5	0	0	0	0
		Sub-Total	**88**	**66**	**22**	**3**	**5**	**2**	**3**	**7**	**2**	**0**	**0**	**0**
	Total		**383**	**269**	**114**	**12**	**43**	**31**	**11**	**11**	**2**	**0**	**4**	**0**

Table B-4 AHP Analysis with PV for Company Statement Analysis Module for Company Y

Com. Stat. Analysis Module	Value Socialisation	Value Integration	PV
Value Socialisation	1	1/2	0.3333
Value Integration	2	1	**0.6667**

Table B-5 AHP Analysis with PV for Financial Analysis Module

Financial Analysis Module	Leverage Ratio	Liquidity Ratio	Efficiency Ratio	Profitability Ratio	PV
Leverage Ratio	1	2	1/3	1/2	0.1676
Liquidity Ratio	1/2	1	1/3	1/2	0.1171
Efficiency Ratio	3	3	1	3	**0.4841**
Profitability Ratio	2	2	1/3	1	0.2311

Table B-6 AHP Analysis with PV for Customer Analysis Module for Company Y

Customer Analysis Module	Customer Satisfaction	Market Share	PV
Customer Satisfaction	1	2	**0.6667**
Market Share	1/2	1	0.3333

Table B-7 AHP Analysis with PV for Internal Business Process Analysis Module for Company Y

Internal Business Process Module	Product Development	After-sale Service	PV
Product Development	1	2	**0.6667**
After-sale Service	1/2	1	0.3333

Table B-8 AHP Analysis with PV for Learning & Growth Analysis Module for Company Y

Learning & Growth Analysis Module	Product Development	After-sale Service	PV
Employee Engagement	1	2	**0.6667**
Social & Environmental Issue	1/2	1	0.3333

Table B-9 AHP Analysis with PV for Level 1 – Business Perspective for Company Y

Business Perspective Level	Comp. Stat. Analysis	Financial Analysis	Customer Analysis	Int. Bus. Proc.	L & G Analysis	PV
Comp. Stat. Analysis	1	1/2	1/2	1/2	1/2	0.1078
Financial Analysis	2	1	2	1/2	2	0.2422
Customer Analysis	2	1/2	1	1/2	2	0.1867
Int. Bus. Proc.	2	2	2	1	2	**0.3200**
L & G Analysis	2	1/2	1/2	1/2	1	0.1433

Table B-10 Summary of AHP Analysis with PV for Level 1 – Business Perspective for Company Y

KBIMSO Level	**Module**	**PV**	**Sub-Module**	**PV**
Level 1 Business Perspective	Company Statement Analysis	0.1078	Value Socialisation	0.3333
			Value Integration	**0.6667**
	Financial Analysis	0.2422	Leverage Ratio	0.1676
			Liquidity Ratio	0.1171
			Efficiency Ratio	**0.4841**
			Profitability Ratio	0.2311
	Customer Analysis	0.1867	**Customer Satisfaction**	**0.6667**
			Market Share	0.3333
	Internal Business Process Analysis	**0.3200**	**Product Development**	**0.6667**
			After-sale Service	0.3333
	Learning & Growth Analysis	0.1433	**Employee Engagement**	**0.6667**
			Social & Environmental Issue	0.3333

Table B-11 Summary of GAP Analysis for Level 2 – Manufacturing Perspective for Company Y

KBIMSO Level	Module	Sub-Module	Number of KB Rules	GAP Analysis for Company Y										
				GP	BP	Problem Category (PC)								
						1	2	3	4	5	6	7	8	9
Level 2 Manufacturing Perspective	Manufacturing Equipment	Organisational Support	47	31	16	3	4	8	1	0	0	0	0	0
		Planning	10	8	2	0	0	0	1	0	1	0	0	0
		Control	26	10	16	0	3	2	4	7	0	0	0	0
		Sub-Total	**83**	**49**	**34**	**3**	**7**	**10**	**6**	**7**	**1**	**0**	**0**	**0**
	Manufacturing Process	Organisational Support	48	41	7	1	0	4	0	0	1	1	0	0
		Planning	49	40	9	2	3	0	1	0	0	0	3	0
		Control	27	17	10	0	0	1	2	7	0	0	0	0
		Sub-Total	**124**	**98**	**26**	**3**	**3**	**5**	**3**	**7**	**1**	**1**	**3**	**0**
	Quality	Organisational Support	48	31	17	7	1	7	1	1	0	0	0	0
		Planning	21	13	8	0	4	0	0	3	1	0	0	0
		Control	12	3	9	0	0	2	2	5	0	0	0	0
		Sub-Total	**81**	**47**	**34**	**7**	**5**	**9**	**3**	**9**	**1**	**0**	**0**	**0**
	Total		**288**	**194**	**94**	**13**	**15**	**24**	**12**	**23**	**3**	**1**	**3**	**0**

Table B-12 AHP Analysis with PV for Manufacturing Equipment Module for Company Y

Mfg. Equipment Module	Org. Support	Planning	Control	PV
Org. Support	1	3	1/2	0.3338
Planning	1/3	1	1/3	0.1416
Control	2	3	1	**0.5247**

Table B-13 AHP Analysis with PV for Manufacturing Process Module for Company Y

Mfg. Process Module	Org. Support	Planning	Control	PV
Org. Support	1	1/2	1/2	0.1976
Planning	2	1	2	**0.4905**
Control	2	1/2	1	0.3119

Table B-14 AHP Analysis with PV for Process Quality Module for Company Y

Process Quality Module	Org. Support	Planning	Control	PV
Org. Support	1	2	2	**0.4905**
Planning	1/2	1	1/2	0.1976
Control	1/2	2	1	0.3119

Table B-15 AHP Analysis with PV for Level 2 – Manufacturing Perspective for Company Y

Mfg. Perspective Level	Mfg. Equipment	Mfg. Process	Process Quality	PV
Mfg. Equipment	1	2	1/2	0.2973
Mfg. Process	1/2	1	1/3	0.1638
Process Quality	2	3	1	**0.5390**

Table B-16 Summary of AHP Analysis with PV for Level 2 – Manufacturing Perspective for Company Y

KBIMSO Level	Module	PV	Sub-Module	PV
Level 2 Manufacturing Perspective	Manufacturing Equipment	0.2973	**Organisational Support**	**0.3338**
			Planning	0.1416
			Control	0.5247
	Manufacturing Process	0.1638	Organisational Support	0.1976
			Planning	**0.4905**
			Control	0.3119
	Process Quality	**0.5390**	**Organisational Support**	**0.4905**
			Planning	0.1976
			Control	0.3119

Table B-17 Summary of GAP Analysis for Level 3 – Maintenance Rules for Company Y

KBIMSO Level	Module	Sub-Module	Number of KB Rules	GAP Analysis for Company Y										
				GP	BP	Problem Category (PC)								
						1	2	3	4	5	6	7	8	9
Level 3 Maintenance Perspective - Maintenance Rules	**Maintenance Policy**	Planning	52	36	16	3	4	6	1	0	1	1	0	0
		Control	29	14	15	0	1	5	3	4	0	0	2	0
		Sub-Total	**81**	**50**	**31**	**3**	**5**	**11**	**4**	**4**	**1**	**1**	**2**	**0**
	Maintenance Organisation	Planning	17	10	7	0	1	1	1	0	0	0	0	4
		Control	11	3	8	0	1	2	1	4	0	0	0	0
		Sub-Total	**28**	**13**	**15**	**0**	**2**	**3**	**2**	**4**	**0**	**0**	**0**	**4**
	Maintenance Inf. & Doc.	Planning	20	15	5	2	3	0	0	0	0	0	0	0
		Control	7	2	5	0	0	3	1	1	0	0	0	0
		Sub-Total	**27**	**17**	**10**	**2**	**3**	**3**	**1**	**1**	**0**	**0**	**0**	**0**
	Total		**136**	**80**	**56**	**5**	**10**	**17**	**7**	**9**	**1**	**1**	**2**	**4**

Table B-18 AHP Analysis with PV for Maintenance Policy Module for Company Y

Maintenance Policy Module	Planning	Control	PV
Planning	1	2	**0.6667**
Control	1/2	1	0.3333

Table B-19 AHP Analysis with PV for Maintenance Organisation Module for Company Y

Maintenance Organisation Module	Planning	Control	PV
Planning	1	1/3	0.2500
Control	3	1	**0.7500**

Table B-20 AHP Analysis with PV for Maintenance Information & Documentation Module for Company Y

Maintenance Inf. & Doc. Module	Planning	Control	PV
Planning	1	1/2	0.3333
Control	2	1	**0.6667**

Table B-21 AHP Analysis with PV for Level 3 – Maintenance Rules for Company Y

Maintenance Rules Level	Maint. Policy	Maint. Organisation	Maint. Inf. & Doc.	PV
Maint. Policy	1	2	1/2	0.3119
Maint. Organisation	1/2	1	1/2	0.1976
Maint. Inf. & Doc.	2	2	1	**0.4905**

Table B-22 Summary of AHP Analysis with PV for Level 3 – Maintenance Rules for Company Y

<table>
<tr><th>KBIMSO Level</th><th>Module</th><th>PV</th><th>Sub-Module</th><th>PV</th></tr>
<tr><td rowspan="6">Level 3 Maintenance Rules</td><td rowspan="2">Maintenance Policy</td><td rowspan="2">0.3119</td><td>Planning</td><td>0.6667</td></tr>
<tr><td>Control</td><td>0.3333</td></tr>
<tr><td rowspan="2">Maintenance Organisation</td><td rowspan="2">0.1976</td><td>Planning</td><td>0.2500</td></tr>
<tr><td>Control</td><td>0.7500</td></tr>
<tr><td rowspan="2">Maintenance Inf. & Doc.</td><td rowspan="2">0.4905</td><td>Planning</td><td>0.3333</td></tr>
<tr><td>Control</td><td>0.6667</td></tr>
</table>

Table B-23 Summary of GAP Analysis for Level 4 – Maintenance Activities for Company Y

KBIMSO Level	Module	Sub-Module	Number of KB Rules	GAP Analysis for Company Y										
				GP	BP	Problem Category (PC)								
						1	2	3	4	5	6	7	8	9
Level 4 Maintenance Perspective - Maintenance Activities	Repairing Activity	Planning	10	3	7	0	3	4	0	0	0	0	0	0
		Control	13	5	8	0	0	0	1	7	0	0	0	0
		Sub-Total	**23**	**8**	**15**	**0**	**3**	**4**	**1**	**7**	**0**	**0**	**0**	**0**
	Retaining Activity	Planning	25	19	6	0	0	6	0	0	0	0	0	0
		Control	13	7	6	0	0	0	2	4	0	0	0	0
		Sub-Total	**38**	**26**	**12**	**0**	**0**	**6**	**2**	**4**	**0**	**0**	**0**	**0**
	Modification Activity	Planning	11	8	3	0	0	1	0	2	0	0	0	0
		Control	6	1	5	0	0	1	0	4	0	0	0	0
		Sub-Total	**17**	**9**	**8**	**0**	**0**	**2**	**0**	**6**	**0**	**0**	**0**	**0**
	Design Activity	Planning	11	10	1	0	0	0	0	1	0	0	0	0
		Control	6	1	5	0	0	0	1	4	0	0	0	0
		Sub-Total	**17**	**11**	**6**	**0**	**0**	**0**	**1**	**5**	**0**	**0**	**0**	**0**
	Total		**95**	**54**	**41**	**0**	**3**	**12**	**4**	**22**	**0**	**0**	**0**	**0**

Table B-24 AHP Analysis with PV for Repairing Activity Module for Company Y

Repairing Activity Module	Planning	Control	PV
Planning	1	3	**0.7500**
Control	1/3	1	0.2500

Table B-25 AHP Analysis with PV for Retaining Activity Module for Company Y

Retaining Activity Module	Planning	Control	PV
Planning	1	1/2	0.3333
Control	2	1	**0.6667**

Table B-26 AHP Analysis with PV for Modification Activity Module for Company Y

Modification Activity Module	Planning	Control	PV
Planning	1	1/3	0.2500
Control	3	1	**0.7500**

Table B-27 AHP Analysis with PV for Design Activity Module for Company Y

Design Activity Module	Planning	Control	PV
Planning	1	1/3	0.2500
Control	3	1	**0.7500**

Table B-28 AHP Analysis with PV for Level 4 – Maintenance Activities for Company Y

Maintenance Activities Level	Repair	Retain	Modification	Design	PV
Repairing Activity	1	2	2	3	**0.4168**
Retaining Activity	1/2	1	1/2	2	0.1928
Modification Activity	1/2	2	1	2	0.2695
Design Activity	1/3	1/2	1/2	1	0.1209

Table B-29 Summary of AHP Analysis with PV for Level 4 – Maintenance Activities for Company Y

KBIMSO Level	**Module**	**PV**	**Sub-Module**	**PV**
Level 4 Maintenance Activities	**Repairing Activity**	**0.4168**	**Planning**	**0.7500**
			Control	0.2500
	Retaining Activity	0.1928	Planning	0.3333
			Control	**0.6667**
	Modification Activity	0.2695	Planning	0.2500
			Control	**0.7500**
	Design Activity	0.1209	Planning	0.2500
			Control	**0.7500**

Table B-30 Summary of GAP Analysis for Level 5 – Maintenance Resource for Company Y

KBIMSO Level	**Module**	**Sub-Module**	**Number of KB Rules**	**GAP Analysis for Company Y**										
				GP	**BP**	**Problem Category (PC)**								
						1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Level 5 Maintenance Perspective - Maintenance Resources	**Maintenance Personnel**	Planning	25	21	4	0	1	2	0	1	0	0	0	0
		Control	16	11	5	0	2	1	0	2	0	0	0	0
		Sub-Total	**41**	**32**	**9**	**0**	**3**	**3**	**0**	**3**	**0**	**0**	**0**	**0**
	Maintenance Tools	Planning	7	5	2	0	1	1	0	0	0	0	0	0
		Control	10	3	7	0	1	1	2	3	0	0	0	0
		Sub-Total	**17**	**8**	**9**	**0**	**2**	**2**	**2**	**3**	**0**	**0**	**0**	**0**
	Maintenance Material	Planning	17	13	4	0	0	4	0	0	0	0	0	0
		Control	8	3	5	0	0	1	1	3	0	0	0	0
		Sub-Total	**25**	**16**	**9**	**0**	**0**	**5**	**1**	**3**	**0**	**0**	**0**	**0**
	Maintenance ICT	Planning	9	4	5	0	1	4	0	0	0	0	0	0
		Control	12	4	8	0	5	2	1	0	0	0	0	0
		Sub-Total	**21**	**8**	**13**	**0**	**6**	**6**	**1**	**0**	**0**	**0**	**0**	**0**
	Total		**104**	**64**	**40**	**0**	**11**	**16**	**4**	**9**	**0**	**0**	**0**	**0**

Table B-31 AHP Analysis with PV for Maintenance Personnel Module for Company Y

Maintenance Personnel Module	Planning	Control	PV
Planning	1	1/2	0.3333
Control	2	1	**0.6667**

Table B-32 AHP Analysis with PV for Maintenance Tools Module for Company Y

Maintenance Tools Module	Planning	Control	PV
Planning	1	1/2	0.3333
Control	2	1	**0.6667**

Table B-33 AHP Analysis with PV for Maintenance Material Module for Company Y

Maintenance Material Module	Planning	Control	PV
Planning	1	1/2	0.3333
Control	2	1	**0.6667**

Table B-34 AHP Analysis with PV for Maintenance ICT Module for Company Y

Maintenance ICT Module	Planning	Control	PV
Planning	1	1/2	0.3333
Control	2	1	**0.6667**

Table B-35 AHP Analysis with PV for Level 5 – Maintenance Resources for Company Y

Maintenance Resources Level	Personnel	Tools	Material	ICT	PV
Personnel	1	1/2	1/2	1/3	0.1202
Tools	2	1	2	1/2	0.2596
Material	2	1/2	1	1/3	0.1707
ICT	3	2	3	1	**0.4495**

Table B-36 Summary of AHP Analysis with PV for Level 5 – Maintenance Resources for Company Y

KBIMSO Level	**Module**	**PV**	**Sub-Module**	**PV**
Level 5 Maintenance Resources	Maintenance Personnel	0.1202	Planning	0.3333
			Control	**0.6667**
	Maintenance Tools	0.2596	Planning	0.3333
			Control	**0.6667**
	Maintenance Material	0.1707	Planning	0.3333
			Control	**0.6667**
	Maintenance ICT	**0.4495**	Planning	0.3333
			Control	**0.6667**

APPENDIX C

KNOWLEDGE-BASE RULES

0.1 Module: Company Environment, SubModule: General Information

Company Profile	Company Name
	Company Address
User Profile	User Name
	Management Level (Top/Middle/Lower Level Management)
	Home Base/Department (Business/Manufacturing/Maintenance)

0.2 Module: Company Environment, SubModule: Company Current State

Company Statement	Vision
	Mission
	Objectives
Company Position in Automotive Industry	Automotive Manufacturer (OEM)/ Automotive Component Provider (First Tier Supplier)/ Automotive Component Provider (Aftermarket)
Company Size	Number of Employees
	Annual turnover
Business Competitiveness	Age of company
	Number of suppliers
	Number of customers
	Number of competitors
Maintenance-focussed Activity	Reliability-Centred Maintenance
	Total Productive Maintenance
	Business-Centred Maintenance
Corporate Sustainability	Social Issue
	Environmental Issue

1.1 Module: Business Perspective, Sub Module: Company Statement Analysis

Dimension	KPI	KB Rule			GAP (PC)
Value socialisation	Company Statement Availability	1	IF	The company understand the importance of company statement for its business organisation	1
	Does the company have the elements of the Company Statement below?				
		1.1a	IF	The company has **vision** statement	1
		1.1b	AND	The company has **mission** statement	1
		1.1c	AND	The company has **objectives** statement	1
			THEN	The company already has a comprehensive company statement (vision, mission, and objectives)	
			OR	The company still needs to complete its company statement (vision, mission, and objectives).	
	Who were involved in developing the Company Statement?				
	Involvement in Creating Company Statement	1.2a	IF	Top Level Management members were involved in creating company statements	1
		1.2b	AND	Middle Level Management members were involved in creating company statements	3
		1.2c	AND	Lower Level Management members were involved in creating company statements	5
			THEN	The company has involved all level of management in creating company statements.	
			OR	The company has not involved all level of management in creating company statements.	
	To make the company members know and understand about values of the company statement:				
	Knowing & Understanding	1.3.1a	IF	The values of company statement are explained during induction session to new staff	4
		1.3.1b	AND	There is a periodic meeting for all company members to get updates about company statement values and future objectives	4
			THEN	The company has socialised its company statement to all company members.	
			OR	The company has not socialised its company statement to all company members.	
	Do the level of managements below understand and can explain the values of the company statement?				
		1.3.2a	AND	Top Level Management can explain the values of company statement	2
		1.3.2b	AND	Middle Level Management can explain the values of company statement	3
		1.3.2c	AND	Lower Level Management can explain the values of company statement	4
			THEN	All level managements have known and understood about the values of company statement.	
			OR	Not all level managements have known and understood about the values of company statement.	
	Where the key aspects of the company statements are visually displayed?				
		1.3.3a	AND	The relevant key aspects of company statement are visually displayed on: # The administrative office	3
		1.3.3b	AND	# The shop floor	3

		1.3.3c	AND	# The customer service office	3
		1.3.3d	AND	# The company website	3
			THEN	The relevant key aspects of company statement have been visually displayed on the required places.	
			OR	The relevant key aspects of company statement have not been visually displayed on the required places yet.	
	The values of the company statement are communicated to the stakeholders:				
		1.3.4a	AND	The values of company statement are communicated to: # Shareholders	3
		1.3.4b	AND	# Customers	3
		1.3.4c	AND	# Suppliers	3
		1.3.4d	AND	# Lenders	3
		1.3.4e	AND	# Others who have interest with the company	3
			THEN	The company has communicated its company statement to the stakeholders.	
			OR	The company has not communicated its company statement to the stakeholders.	
Value integration	Value empowerment	2.1a	IF	Mission statement is considered as the organisational goal to be achieved	1
		2.1b	AND	Mission statement is considered as the cornerstone to develop measurable and achievable objectives	1
		2.1c	AND	Company statement is considered to influence work culture and behaviour	1
		2.1d	AND	Company statements is considered to create organisational integration (team work) for all members to work on the same direction	1
		2.1e	AND	Any achievement in implementing company statements is praised with the reward system	2
			THEN	The company statement (especially mission statement) has been strong enough to assist objectives and organisation culture.	
			OR	The company statement (especially mission statement) has not been strong enough to assist objectives and organisation culture.	
	Stakeholders Concerns	2.2a	IF	The company brings shareholders concern in the company statement	2
		2.2b	AND	The company brings customers concern in the company statement	2
		2.2c	AND	The company brings community concern in the company statement	2
		2.2d	AND	The company brings suppliers concern in the company statement	2
		2.2e	AND	The company brings employees concern in the company statement	2
			THEN	The company has clearly specified its concern to meet key stakeholders needs in the company statement.	
			OR	The company has not clearly specified its concern to meet key stakeholders needs in the company statement.	
	Commitment & Support	2.3a	IF	The management team recognise their responsibility in promoting, communicating and achieving company statement	2
		2.3b	AND	The management team are considered as the role-model to implement company statement	2
		2.3c	AND	The management team encourage their employees to work as a teamwork to achieve company statement	2

		2.3d	AND	The management team can match the company value with personal value	2
			THEN	The management team has shown a strong commitment and support to implement the company statement.	
			OR	The management team has not shown a strong commitment and support to implement the company statement.	

1.2 Module: Business Perspective, Sub Module: Financial Perspective

Dimension	KPI	KB Rule			GAP (PC)
Leverage Ratio	Debt Ratio	1a	IF	Debt Ratio in last year ≤ 0.5	2
		1b	AND	Debt Ratio in two years ago ≤ 0.5	3
		1c	AND	Debt Ratio in three years ago ≤ 0.5	3
		1d	AND	Debt Ratio in last year ≤ Debt Ratio in two years ago	2
		1e	AND	Debt Ratio in two years ago ≤ Debt Ratio in three years ago	3
			THEN	Debt Ratios had positive trend and values in three consecutive years.	
			OR	Debt Ratios had negative trend and values in three consecutive years.	
			OR	Debt Ratios fluctuated in three consecutive years.	
			OR	Debt Ratios remained unchanged in three consecutive years.	
	Debt Equity Ratio	2a	IF	Debt Equity Ratio in last year ≤ 0.5	2
		2b	AND	Debt Equity Ratio in two years ago ≤ 0.5	3
		2c	AND	Debt Equity Ratio in three years ago ≤ 0.5	3
		2d	AND	Debt Equity Ratio in last year ≤ Debt Equity Ratio in two years ago	2
		2e	AND	Debt Equity Ratio in two years ago ≤ Debt Equity Ratio in three years ago	3
			THEN	Debt Equity Ratios had positive trend and values in three consecutive years.	
			OR	Debt Equity Ratios had negative trend and values in three consecutive years.	
			OR	Debt Equity Ratios fluctuated in three consecutive years.	
			OR	Debt Equity Ratios remained unchanged in three consecutive years.	
	Times Interest Earned Ratio	3a	IF	Times Interest Earned Ratio in last year ≥ 1	2
		3b	AND	Times Interest Earned Ratio in two years ago ≥ 1	3
		3c	AND	Times Interest Earned Ratio in three years ago ≥ 1	3
		3d	AND	Times Interest Earned Ratio in last year ≥ Times Interest Earned Ratio in two years ago	2
		3e	AND	Times Interest Earned Ratio in two years ago ≥ Times Interest Earned Ratio in three years ago	3
			THEN	Times Interest Earned Ratios had positive trend and values in three consecutive years.	

			OR	Times Interest Earned Ratios had negative trend and values in three consecutive years.	
			OR	Times Interest Earned Ratios fluctuated in three consecutive years.	
			OR	Times Interest Earned Ratios remained unchanged in three consecutive years.	
Liquidity Ratio	Current Ratio	4a	IF	Current Ratio in last year ≥ 1	2
		4b	AND	Current Ratio in two years ago ≥ 1	3
		4c	AND	Current Ratio in three years ago ≥ 1	3
		4d	AND	Current Ratio in last year ≥ Current Ratio in two years ago	2
		4e	AND	Current Ratio in two years ago ≥ Current Ratio in three years ago	3
			THEN	Current Ratios had positive trend and values in three consecutive years.	
			OR	Current Ratios had negative trend and values in three consecutive years.	
			OR	Current Ratios remained unchanged in three consecutive years.	
			OR	Current Ratios fluctuated in three consecutive years.	
	Cash Ratio	5a	AND	Cash Ratio in last year ≥ 1	2
		5b	AND	Cash Ratio in two years ago ≥ 1	3
		5c	AND	Cash Ratio in three years ago ≥ 1	3
		5d	AND	Cash Ratio in last year ≥ Cash Ratio in two years ago	2
		5e	AND	Cash Ratio in two years ago ≥ Cash Ratio in three years ago	3
			THEN	Cash Ratios had positive trend and values in three consecutive years.	
			OR	Cash Ratios had negative trend in three consecutive years.	
			OR	Cash Ratios remained unchanged in three consecutive years.	
			OR	Cash Ratios fluctuated in three consecutive years.	
	Quick Ratio	6a	IF	Quick Ratio in last year ≥ 1	2
		6b	AND	Quick Ratio in two years ago ≥ 1	3
		6c	AND	Quick Ratio in three years ago ≥ 1	3
		6d	AND	Quick Ratio in last year ≥ Quick Ratio in two years ago	2
		6e	AND	Quick Ratio in two years ago ≥ Quick Ratio in three years ago	3
			THEN	Quick Ratios had positive trend in three consecutive years.	
			OR	Quick Ratios had negative trend in three consecutive years.	
			OR	Quick Ratios remained unchanged in three consecutive years.	
			OR	Quick Ratios fluctuated in three consecutive years.	
Efficiency Ratio	Asset Turnover Ratio	7a	IF	Asset Turnover Ratio in last year ≥ 1	2
		7b	AND	Asset Turnover Ratio in two years ago ≥ 1	3

		7c	AND	Asset Turnover Ratio in last year ≥ Asset Turnover Ratio in two years ago	2
			THEN	Asset Turnover Ratios had positive trend in three consecutive years.	
			OR	Asset Turnover Ratios had negative trend in three consecutive years.	
			OR	Asset Turnover Ratios remained unchanged in three consecutive years.	
	Inventory Turnover Ratio	8a	AND	Inventory Turnover Ratio in last year ≥ 1	2
		8b	AND	Inventory Turnover Ratio in two years ago ≥ 1	3
		8c	AND	Inventory Turnover Ratio in last year ≥ Inventory Turnover Ratio in two years ago	2
			THEN	Inventory Turnover Ratios had positive trend in three consecutive years.	
			OR	Inventory Turnover Ratios had negative trend in three consecutive years.	
			OR	Inventory Turnover Ratios remained unchanged in three consecutive years.	
Profitability Ratio	Net Profit Margin Ratio	9a	IF	Net Profit Margin Ratio in last year ≥ Net Profit Margin Ratio in two years ago	2
		9b	AND	Net Profit Margin Ratio in two years ago ≥ Net Profit Margin Ratio in three years ago	3
		9c	AND	The value of Net Profit Margin Ratio in last year is positive	2
		9d	AND	The value of Net Profit Margin Ratio in two years ago is positive	3
		9e	AND	The value of Net Profit Margin Ratio in three years ago is positive	3
			THEN	Net Profit Margin Ratios had positive trend in three consecutive years.	
			OR	Net Profit Margin Ratios had negative trend in three consecutive years.	
			OR	Net Profit Margin Ratios remained unchanged in three consecutive years.	
			OR	Net Profit Margin Ratios fluctuated in three consecutive years.	
	Return on Assets (ROA) Ratio	10a	IF	Return on Assets Ratio (ROA) in last year ≥ ROA in two years ago	2
		10b	AND	The value of ROA in last year is positive	2
		10c	AND	The value of ROA in two years ago is positive	3
			THEN	Return on Assets Ratios had positive trend in three consecutive years.	
			OR	Return on Assets Ratios had negative trend in three consecutive years.	
			OR	Return on Assets Ratios remained unchanged in three consecutive years.	
	Return on Equity (RoE) Ratio	11a	IF	Return on Equity Ratio (ROE) in last year ≥ ROE in two years ago	2
		11b	AND	The value of ROE in last year is positive	2
		11c	AND	The value of ROE in two years ago is positive	3
			THEN	Return on Equity Ratios had positive trend in three consecutive years.	
			OR	Return on Equity Ratios had negative trend in three consecutive years.	
			OR	Return on Equity Ratios remained unchanged in three consecutive years.	
	Return on Investment (ROI) Ratio	12a	AND	Return on Investment Ratio (ROI) in last year ≥ ROI in two years ago	2

		12b	AND	Return on Investment Ratio (ROI) in two year ≥ ROI in three years ago	3
		12c	AND	The value of ROI in last year is positive	2
		12d	AND	The value of ROI in two years ago is positive	3
		12e	AND	The value of ROI in three years ago is positive	3
			THEN	Return on Investment Ratios had positive trend in three consecutive years.	
			OR	Return on Investment Ratios had negative trend in three consecutive years.	
			OR	Return on Investment Ratios remained unchanged in three consecutive years.	
			OR	Return on Investment Ratios fluctuated in three consecutive years.	

1.3 Module: Business Perspective, Sub Module: Customer Perspective

Dimension	KPI	KB Rule			GAP (PC)
Customer Satisfaction - Commitment		1	IF	The company considers that Customer Satisfaction is important for its business	9
2	**Please respond to the statements below related to management commitment on Customer Satisfaction:**				
	Customer Satisfaction (management commitment)	2a	IF	The company has Customer Satisfaction policies or any formal document related to Customer Satisfaction	1
		2b	AND	Top Level Management is involved on creating Customer Satisfaction policies	1
		2c	AND	Top Level Management is involved on developing Customer Satisfaction plans/programmes	1
		2d	AND	Top Level Management is involved on reviewing Customer Satisfaction plans/programmes	1
		2e	AND	Top Level Management links relevant functions to Customer Satisfaction policies and programmes	1
		2f	AND	The company develops infrastructure for Customer Satisfaction programmes	1
		2g	AND	The company allocates specific budget to implement Customer Satisfaction programmes	1
		2h	AND	The company allocates specific human resources for Customer Satisfaction programmes	1
		2i	AND	The company defines job description for Customer Satisfaction employees	1
		2j	AND	The company provides specific training for employees who work on Customer Satisfaction programmes.	1
		2k	AND	There are Key Performance Indicators (KPIs) to measure performance achievement on Customer Satisfaction	2
		2l	AND	The company sets the performance targets of Customer Satisfaction programmes	2
		2m	AND	The company considers benchmark to set the performance target	3
		2n	AND	The Customer Satisfaction policies and programmes are communicated through the organisation	3
			THEN	The company has a strong commitment to achieve Customer Satisfaction.	

			OR	The company has not fully committed to achieve Customer Satisfaction.	
3	**Which functions contribute to the implementation of Customer Satisfaction programmes?**				
	Integration & Collaboration	3a	AND	Marketing function	1
		3b	AND	Manufacturing function	1
		3c	AND	Engineering function	1
		3d	AND	Quality function	1
		3e	AND	Procurement function	1
		3f	AND	Maintenance function	1
		3g	AND	Research and Development function	1
		3h	AND	Human and Resource Development function	4
			THEN	The related functions have been integrated and collaborated in order to achieve Customer Satisfaction.	
			OR	The related functions have not been integrated and collaborated in order to achieve Customer Satisfaction.	
4	**Please respond to the statements below related to evaluation on Customer Satisfaction programmes:**				
	Evaluation	4a	AND	The company reviews its performance on Customer Satisfaction Programmes regularly	2
		4b	AND	The company takes the feedback from relevant staff regarding performance of Customer Satisfaction programmes	2
		4c	AND	The evaluation result is communicated through the organisation	2
			THEN	The management team had a formal process to review Customer Satisfaction programme performance and use it as the feedback to improve future programmes.	
			OR	The management team had no formal process to review Customer Satisfaction programme performance.	
Cust Satisfaction Factors	CS factor (response time)	5	IF	The company considers 'response time' as important factor to achieve Customer Satisfaction	1
		5a	AND	In Customer Satisfaction programme related to 'response time', the company takes into account: # Time required for new product development	1
		5b	AND	# Scheduling of manufacturing process	1
		5c	AND	# Maintaining the manufacturing equipment	1
		5d	AND	# Product Lead Time	1
		5e	AND	# Delivery speed in reaching customer order	1
			THEN	The company has recognised critical factors to reach Customer Satisfaction in term of response time.	
			OR	The company has not recognised critical factors to reach Customer Satisfaction in term of response time.	

	CS factor (quality)	6	IF	The company considers 'quality of product' as important factor to achieve Customer Satisfaction	1
		6a	AND	In Customer Satisfaction programme related to 'quality of product', the company takes into account: # Product performance	1
		6b	AND	# Product features	1
		6c	AND	# Product reliability	1
		6d	AND	# Product conformance	1
		6e	AND	# Product durability	1
		6f	AND	# Product serviceability	1
		6g	AND	# Product aesthetics	1
		6h	AND	# Perceived quality of product	1
			THEN	The company has recognised critical factors to reach Customer Satisfaction in term of quality.	
			OR	The company has not recognised critical factors to reach Customer Satisfaction in term of quality.	
	CS factor (safety)	7	IF	The company considers 'safety of product' as important factor to achieve Customer Satisfaction	1
		7a	AND	In Customer Satisfaction programme related to 'product safety', the company takes into account: # Safety of material used	1
		7b	AND	# Safety in product design (shape)	1
		7c	AND	# Safety in used/worn/operated	1
		7d	AND	# Safety to environment	1
			THEN	The company has recognised critical factors to reach Customer Satisfaction in term of safety of product.	
			OR	The company has not recognised critical factors to reach Customer Satisfaction in term of safety of product.	
	CS factor (price)	8	IF	The company considers 'price' as important factor to reach Customer Satisfaction	1
		8a	AND	In Customer Satisfaction programme related to 'price', the company takes into account: # Its competitive strategy regarding price	1
		8b	AND	# Competitors price for similar level of quality of product	1
		8c	AND	# Niche product	1
		8d	AND	# Product Life Cycle	1
		8e	AND	# Intangible aspects of product	1
			THEN	The company has recognised critical factors to reach Customer Satisfaction in term of price.	
			OR	The company has not recognised critical factors to reach Customer Satisfaction in term of price.	
	CS factor (intangible)	9	IF	The company considers 'image' as important factor to reach Customer Satisfaction	2
		9a	AND	In Customer Satisfaction programme related to 'image', the company takes into account: # Creating unique brand (symbol)	2
		9b	AND	# Creating perceived image when using the product/service	2

		9c	AND	# Providing professional catalogue to represent all variety of products and their specifications	2
		10	AND	The company considers 'reputation' as important factor to reach Customer Satisfaction	2
		10a	AND	In Customer Satisfaction programme related to 'reputation', the company takes into account: # Equivalent/consistent quality on specific products/services	2
		11	AND	The company considers 'relationship' as important factor to reach Customer Satisfaction	2
		11a	AND	In Customer Satisfaction programme related to 'relationship', the company takes into account: # Sending letter to customers to inform new product/service	2
		11b	AND	# Sending letter to customers related to achievement and improvement obtained by the company	2
		11c	AND	# Advertise new product/service with variety of method	2
		11d	AND	# Develop a professional website to provide up to date information about the company activities, its products/services and other supporting facilities	2
		11e	AND	# Providing knowledgeable and responsive people to help the customers to get the suitable product/service	2
		11f	AND	# Providing special offers/facilities for loyal customers	2
			THEN	The company has recognised critical factors to reach Customer Satisfaction on intangible aspect.	
			OR	The company has not recognised critical factors to reach Customer Satisfaction on intangible aspect.	
Cust Satisfaction Control		12a	AND	The achievement of Customer Satisfaction programmes is measured through Customer Satisfaction survey	2
		12b	AND	The achievement of Customer Satisfaction programmes is measured through Customer Retention	3
		12c	AND	The achievement of Customer Satisfaction programmes is measured through Customer Acquisition	3
		12d	AND	The achievement of Customer Satisfaction programmes is measured through Customer Profitability	3
		12e	AND	The achievement of Customer Satisfaction programmes is measured through Market Share	2
			THEN	The company has measured Customer Satisfaction achievement properly.	
			OR	The company has not measured Customer Satisfaction achievement properly.	
Market Share (4)		13	IF	The company understand the importance of measuring market share of its product	9
Market Share Identification	MS Identification: National	14a	IF	The company knows the National Market Place (addressable market) of its product/service	1
		14b	AND	The number of national competitors is obviously identified	1
		14c	AND	The company measured National Market Share of its products	1
		14d	AND	The company sets the targets for National Market Share	1
		14e	AND	The company considers benchmark to set the target for National Market Share	1
			THEN	The company has identified and assessed its National Market Share properly.	
			OR	The company has not identified and assessed its National Market Share properly.	

	MS Identification: International	15a	IF	the company knows the International Market Place (addressable market) of its product/service	3
		15b	AND	The number of international competitors is obviously identified	3
		15c	AND	The company measured International Market Share of its products	3
		15d	AND	The company sets the targets for International Market Share	3
		15e	AND	The company considers benchmark to set the target for International Market Share	3
			THEN	The company has identified and assessed its International Market Share properly.	
			OR	The company has not identified and assessed its International Market Share properly.	
	MS Identification: Global	16a	IF	The company knows the Global Market Place (addressable market) of its product/service	4
		16b	AND	The number of global competitors is obviously identified	4
		16c	AND	The company measured Global Market Share of its products	4
		16d	AND	The company sets the targets for Global Market Share	4
		16e	AND	The company considers benchmark to set the target for Global Market Share	4
			THEN	The company has identified and assessed its Global Market Share properly.	
			OR	The company has not identified and assessed its Global Market Share properly.	
Market Share Achievement	Market Share Achievement	17a	AND	The trend of National Market Share in the last five years is positive	2
		17b	AND	The trend of International Market Share in the last five years is positive	3
		17c	AND	The trend of Global Market Share in the last five years is positive	4
			THEN	The company had positive trends on Market Share in the last five years.	
			OR	The company had negative trends or fluctuations on Market Share in the last five years.	

1.4 Module: Business Perspective, Sub Module: Internal Business Process Perspective

Dimension	KPI	KB Rule	KB Rule		GAP (PC)
Product Development - Commitment		1	IF	The company considers that Product Development is important for its business	9
2	**Please respond to the statements below related to management commitment on Product Development:**				
	Product Development (management commitment)	2a	IF	The company has Product Development policies or any formal document related to Product Development	1
		2b	AND	Top Level Management is involved on creating Product Development policies	1
		2c	AND	Top Level Management is involved on developing Product Development plans/programmes	1

		2d	AND	Top Level Management is involved on reviewing Product Development plans/programmes	1
		2e	AND	Top Level Management links relevant functions to Product Development policies and programmes	1
		2f	AND	The company develops infrastructure for Product Development programmes	1
		2g	AND	The company allocates specific budget to implement Product Development programmes	1
		2h	AND	The company allocates specific human resources for Product Development programmes	1
		2i	AND	The company defines job description for Product Development employees	1
		2j	AND	The company provides specific training for employees who work on Product Development programmes	1
		2k	AND	There are Key Performance Indicators (KPIs) to measure performance achievement on Product Development	2
		2l	AND	The company sets the performance targets of Product Development programmes	2
		2m	AND	The company considers benchmark to set the performance target	3
		2n	AND	The Product Development policies and programmes are communicated through the organisation	3
			THEN	The company has shown a strong commitment to support Product Development programmes.	
			OR	The company has not shown a strong commitment to support Product Development programmes.	
3	**Which functions contribute to the implementation of Product Development programmes?**				
	Integration & Collaboration	3a	AND	Functions that contribute to the implementation of Product Development programmes: # Marketing function	1
		3b	AND	# Research and Development function	1
		3c	AND	# Manufacturing function	1
		3d	AND	# Engineering function	1
		3e	AND	# Maintenance function	1
		3f	AND	# Quality function	1
		3g	AND	# Procurement function	1
		3h	AND	# Human and Resource Development function	4
			THEN	The related functions have been integrated and collaborated in order to support Product Development programmes.	
			OR	The related functions have not been integrated and collaborated properly in order to support Product Development programmes.	
4	**Please respond to the statements below related to evaluation on Product Development programmes:**				
	Evaluation	4a	AND	The company reviews its performance on Product Development programmes regularly	2
		4b	AND	The company takes the feedback from relevant staff regarding performance of Product Development programmes	2
		4c	AND	The evaluation result is communicated through the organisation	2
			THEN	The management team had a formal process to review Product Development programme performance and use it as the feedback to improve future programmes.	

			OR	The management team had no formal process to review Product Development programme performance and use it as the feedback to improve future programmes.	
Product Dev - Market Research		5	IF	The company considers the importance of 'market research' as initial process of product development process	9
6	**The company takes these factors below into account to understand its market place:**				
	Understand Market Place	6a	IF	The company understands about: # Customer requirements regarding product specification	2
		6b	AND	# Market size	2
		6c	AND	# Customer behaviour	2
		6d	AND	# Geographic condition	2
		6e	AND	# Seasonality	2
		6f	AND	# Culture	2
		6g	AND	# Ethics	2
		6h	AND	# Laws	2
			THEN	The company has understood the suitable product specification or service in different market place.	
			OR	The company has not understood properly the suitable product specification or service in different market place.	
7	**The company takes these factors below into account to identify market segment:**				
	Market Segment Identification	7a	IF	The company understands about purchasing behaviour of particular market segment	2
		7b	AND	The company is aware of the level of customer satisfaction	2
		7c	AND	The company can decide the value proposition of its product to meet customer needs	2
			THEN	The company can successfully decide the market segment for its product and service.	
			OR	The company cannot successfully decide the market segment for its product and service.	
8	**Please confirm the statements below related to Product Assimilation:**				
	Product Assimilation	8a	IF	The company can estimate the demand of product in term of quantity	2
		8b	AND	The company can estimate the demand of product in term of variety	2
		8c	AND	The company can estimate the demand of product in term of frequency of order	2
		8d	AND	The company understands customer expectation in term of product quality	2
		8e	AND	The company understands customer expectation in term of delivery speed	2
		8f	AND	The company understands customer expectation in term of price	2
			THEN	The company has assimilated the customer expectation regarding its product/service.	
			OR	The company has not assimilated the customer expectation regarding its product/service.	
9	**The company takes these factors below into account to identify its competitor(s):**				
	Competitor Identification	9a	IF	The company is aware of its competitors and their capabilities	2

		9b	AND	The company understands the product or service they are offered	2
		9c	AND	The company is aware of value proposition of such product or service	2
		9d	AND	The company is aware of the competitor(s) marketing strategy	2
		9e	AND	The company considers competitors strategy as an input to develop its own strategy	2
			THEN	The company has known its competitors and how to create competitive value and strategy of its product against competitors.	
			OR	The company has not known its competitors and how to create competitive value and strategy of its product against competitors.	
Product Dev - Product Innovation		10	IF	The company considers the importance of 'product innovation' as part of product development process	9
		11	IF	The company conducts 'product innovation' as part of product development process	1
	Product Innovation (time)	12	IF	Related to product innovation, the company takes into account reducing cycle time	2
		12a	AND	In term of reducing cycle time on Product Innovation, the company takes into account: # Developing the relationship with suppliers in order to achieve on-time delivery	3
		12b	AND	# Developing a supporting system to enable iteration of development process	3
		12c	AND	# Facilitating a supporting system for cross functional integration	3
		12d	AND	# Engaging with research centres or universities to reduce cycle time	3
		12e	AND	# Engaging with the new technology to reduce cycle time	3
		12f	AND	# Engaging with the new methodologies to reduce cycle time	3
			THEN	The company has shown a good concern to reduce cycle time on Product Development.	
			OR	The company has not shown a good concern to reduce cycle time on Product Development.	
	Product Innovation (quality)	13	AND	Related to product innovation, the company takes into account increasing quality	2
		13a	AND	In term of increasing quality on Product Innovation, the company takes into account: # Developing the relationship with suppliers in order to achieve product specification	3
		13b	AND	# Facilitating collaboration between internal functions and suppliers	3
		13c	AND	# Facilitating collaboration between internal functions with customers	3
		13d	AND	# Maintaining manufacturing equipment to work at its required performance level	3
		13e	AND	# Developing built-in quality on manufacturing process	3
		13f	AND	# Engaging with research centres or universities to improve quality	3
		13g	AND	# Engaging with the new technology to improve quality	3
		13h	AND	# Engaging with the new methodologies to improve quality	3
			THEN	The company has shown a good concern to improve quality on Product Development.	

			OR	The company has not shown a good concern to improve quality on Product Development.	
	Product Innovation (cost)	14	AND	Related to product innovation, the company takes into account reducing cost	2
		14a	AND	In term of reducing cost on Product Innovation, the company takes into account: # Developing the relationship with suppliers in order to provide low cost materials	3
		14b	AND	# Considering product complexity and variety	3
		14c	AND	# Engaging with research centres or universities to reduce cost	3
		14d	AND	# Engaging with the new technology to reduce cost	3
		14e	AND	# Engaging with the new methodologies to reduce cost	3
			THEN	The company has shown a good concern to reduce cost on Product Development.	
			OR	The company has not shown a good concern to reduce cost on Product Development.	
After-sale Service		15	IF	The company considers that After-sale Service is important for its business	9
16	**Please respond to the statements below related to management commitment on After-sale Service:**				
After-sale Service - Commitment	After-sale Service (management commitment)	16a	IF	The company has After-sale Service policies or any formal document related to After-sale Service	1
		16b	AND	Top Level Management is involved on creating After-sale Service policies	1
		16c	AND	Top Level Management is involved on developing After-sale Service plans/programmes	1
		16d	AND	Top Level Management is involved on reviewing After-sale Service plans/programmes	1
		16e	AND	Top Level Management links relevant functions to After-sale Service policies and programmes	1
		16f	AND	The company develops infrastructure for After-sale Service programmes	1
		16g	AND	The company allocates specific budget to implement After-sale Service programmes	1
		16h	AND	The company allocates specific human resources for After-sale Service programmes	1
		16i	AND	The company defines job description for After-sale Service employees.	1
		16j	AND	The company provides specific training for employees who work on After-sale Service programmes	1
		16k	AND	There are Key Performance Indicators (KPIs) to measure performance achievement on After-sale Service	2
		16l	AND	The company sets the performance targets of After-sale Service programmes	2
		16m	AND	The company considers benchmark to set the performance target	3
		16n	AND	The After-sale Service policies and programmes are communicated through the organisation	3
			THEN	The company has shown a strong commitment to support After-sale Service programmes.	
			OR	The company has not shown a strong commitment to support After-sale Service programmes.	
17	**Which functions contribute to the implementation of After-sale Service programmes?**				
	Integration & Collaboration	17a	AND	Functions that contribute to the implementation of Product Development programmes: # Marketing function	1
		17b	AND	# Quality function	1
		17c	AND	# Engineering function	1

		17d	AND	# Manufacturing function	1
		17e	AND	# Research and Development function	4
		17f	AND	# Maintenance function	4
		17g	AND	# Procurement function	4
		17h	AND	# Human and Resource Development function	4
			THEN	The related functions have been integrated and collaborated in order to support After-sale Service programmes.	
			OR	The related functions have not been integrated and collaborated in order to support After-sale Service programmes.	
18	**Please respond to the statements below related to evaluation on After-sale Service programmes:**				
	Evaluation	18a	AND	The company reviews its performance on After-sale Service programmes regularly	2
		18b	AND	The company takes the feedback from relevant staff regarding performance of After-sale Service programmes	2
		18c	AND	The evaluation result is communicated through the organisation	2
			THEN	The company had a formal process to review After-sale Service programme performance and use it as the feedback to improve future programmes.	
			OR	The company had no formal process to review After-sale Service programme performance and use it as the feedback to improve future programmes.	
19	**Please respond to the statements below related to After-sale Service programmes:**				
After-sale Service Factors	programmes	19a	AND	There are policies and procedures for product warranty	2
		19b	AND	There are policies and procedures for product repair	2
		19c	AND	There are policies and procedures for product recall	2
		19d	AND	There are policies and procedures to support customers to upgrade their old product/service	2
		19e	AND	Original spare parts are available on every dealer	2
			THEN	After-sale Service programmes has covered important services to support the customer after purchasing product.	
			OR	After-sale Service programmes has not covered important services to support the customer after purchasing product.	
	centres (dealers)	20	IF	The customer service centres (dealers) are available to support after-sale service	2
	Please respond to the statements below related to After-sale Service Centres (Dealers):				
		20a	AND	# The number of customer service centres (dealers) and position relative to proportion of market share in a specific market place	3
		20b	AND	# The facilities and service supports are comprehensive and standardized on all dealers	3
		20c	AND	# There is a consultation facilities to help customers to discuss their problem	3

	centres (online)	21	AND	Online customer service centres are available to support after-sale service	3
22	Please respond to the statements below related to Online After-sale Service Centre:				
		22a	AND	Online customer service is available in term of: # Call centre	4
		22b	AND	# Website	4
		23a	AND	The online customer service centre take into account: # 24/7 access	4
		23b	AND	# Informing the customer the nearest customer service centre	4
		23c	AND	# Providing up to date information about after-sale service	4
		23d	AND	# Providing quick reply on queries or complains	4
		23e	AND	# Facilitating order of spare part(s)	4
		23f	AND	# Facilitating booking of dealer service	4
			THEN	The company has provided adequate service centres to support After-sale Service programmes	
			OR	The company has not provided adequate service centres to support After-sale Service programmes	
	documentation	24a	AND	There is a documentation system to record After-sale Service history of product	2
		24b	AND	There is a documentation system to record information to improve After-sale Service performance	2
			THEN	After-sale Service is well documented to support After-sale Service programmes and future improvement.	
			OR	After-sale Service is not well documented to support After-sale Service programmes and future improvement.	

1.5 Module: Business Perspective, Sub Module: Learning and Growth Perspective

Dimension	KPI	KB Rule	KB Rule		GAP (PC)
Employee Engagement		1	IF	The company considers that Employee Engagement is important for its business	9
2	**Please respond to the statements below related to management commitment on Employee Engagement:**				
Empl Engagement - Commitment	Employee Engagement (management commitment)	2a	IF	The company has Employee Engagement policies or any formal document related to Employee Engagement	1
		2b	AND	Top Level Management is involved on creating Employee Engagement policies	1
		2c	AND	Top Level Management is involved on developing Employee Engagement plans/programmes	1
		2d	AND	Top Level Management is involved on reviewing Employee Engagement plans/programmes	1
		2e	AND	Top Level Management links relevant functions to Employee Engagement policies and programmes	1
		2f	IF	The company develops infrastructure for Employee Engagement programmes	1
		2g	AND	The company allocates specific budget to implement Employee Engagement programmes	1

		2h	AND	The company allocates specific human resources for Employee Engagement programmes	1
		2i	AND	The company defines job description for employees who work on Employee Engagement programmes	1
		2j	AND	The company provides specific training for employees who work on Employee Engagement programmes	1
		2k	AND	The company defines Key Performance Indicators (KPIs) to measure performance achievement of Employee Engagement programmes	2
		2l	AND	The company sets the performance targets of Employee Engagement programmes	2
		2m	AND	The company considers benchmark to set the performance target	3
		2n	AND	The Employee Engagement policies and programmes are communicated through the organisation	3
			THEN	The company has a strong commitment to achieve Employee Engagement.	
			OR	The company has not fully committed to achieve Employee Engagement.	
	Integration & Collaboration	3a	AND	Functions that contribute to the implementation of Employee Engagement programmes: # Human and Resource Development function	1
		3b	AND	# Quality function	4
		3c	AND	# Engineering function	4
		3d	AND	# Manufacturing function	4
		3e	AND	# Research and Development function	4
		3f	AND	# Maintenance function	4
		3g	AND	# Procurement function	4
		3h	AND	# Marketing function	4
			THEN	The relevant functions have collaborated to support Employee Engagement programmes.	
			OR	The relevant functions have not fully collaborated to support Employee Engagement programmes.	
	Evaluation	4a	AND	The company reviews the performance of Employee Engagement programmes regularly	2
		4b	AND	The company takes the feedback from relevant staff regarding performance of Employee Engagement programmes	2
		4c	AND	The evaluation result is communicated through the organisation	2
			THEN	The management team had a formal process to review Employee Engagement programme performance and use it as the feedback to improve future programmes.	
			OR	The management team had no formal process to review Employee Engagement programme performance and use it as the feedback to improve future programmes.	
Empl Engagement Factors		**5**	IF	The company considers that fulfilling employee needs is important aspect of Employee Engagement	9
	career information	6	AND	The company keeps monitoring any changes in the employee laws or industrial regulations	2
7	**Please confirm if the company provides the employees with clear and structured information about:**				

		7a	AND	Right and obligation	2
		7b	AND	Job description and procedures	2
		7c	AND	Career plan	3
		7d	AND	Rate of salary and benefits	3
		7e	AND	Promotion scheme	4
		7f	AND	Rotation scheme	4
		7g	AND	Reward scheme	6
			THEN	The company has provided transparent career information for its employees.	
			OR	The company has not fully provided transparent career information for its employees.	
8	**How does the company prescribe the rate of salary & benefit?**				
	compensation	8a	IF	Rate of salary is competitive referring to skill and risk within the company	2
		8b	AND	Rate of salary is competitive compared to the competitor's company	2
		8c	AND	The company provides health insurance	2
		8d	AND	The company pay the employee taxes and National Insurance	2
		8e	AND	The company provides profit sharing or sales commission or other pays related to achievement and job performance	4
		8f	AND	The company provides transportation expense or company car	6
		8g	AND	The company provides communication expense	6
		8h	AND	The company provides other additional benefits not mention above	6
			THEN	The company has provided competitive salary and benefits to attract employees to retain their position	
			OR	The company has not fully provided competitive salary and benefits to attract employees to retain their position	
9	**Does the company has the skill improvement programmes below?**				
	Skill Improvement	9a	IF	# Continuing formal education	2
		9b	AND	# Vocational training	2
		9c	AND	# Organisational skill training	2
		9d	AND	# Health and safety training	2
			THEN	The company has fully facilitated the employees with skill improvement programmes.	
			OR	The company has not fully facilitated the employees with skill improvement programmes.	
10	**How does the company concern on the employees' facilities to work?**				
	facilities - physical	10a	AND	The required facilities to complete the tasks are available and adequate	3
		10b	AND	The work place is comfortable and designed on ergonomic perspective	3
	facilities - safety	10c	AND	The company has job safety analysis	3

		10d	AND	The company provide safety tools and equipment	3
	facilities - personal	10e	AND	The facilities for personal needs are available to use	3
			THEN	The company has provided facilities both intellectual and physical to support the employees comfortable with their work.	
			OR	The company has not provided adequate facilities both intellectual and physical to support the employees comfortable with their work.	
11	**How does the company concern on the employees' information access to accomplish the tasks?**				
(*)	Information Availability	11a*	IF	The employees have access to the information required to complete their task	2
(*)		11b*	AND	The information required is up to date	2
(*)		11c*	AND	The employees is facilitated to communicate to and work on cross-functional team to complete their task	2
			THEN	The company has fulfilled employee professional needs in order to achieve Employee Engagement.	
			OR	The company has not fulfilled employee professional needs in order to achieve Employee Engagement.	
12	**Please confirm if the leadership and corporate culture below are exist in your company:**				
	Leadership & Corporate Culture	12a	AND	The senior managers are consistent between words and actions	3
		12b	AND	The senior managers make good decisions on their authority	3
		12c	AND	The senior managers develop communication with the employees	3
		12d	AND	The senior managers encourage the employees to be creative and use initiative	3
		12e	AND	The senior managers have high expectation for the employees	3
		12f	AND	The immediate supervisors involve the employees in the decision making process	3
		12g	AND	The immediate supervisors conducts brainstorming to get input for decision making	3
		12h	AND	The immediate supervisors develop communication with the employees to understand their needs	3
		12i	AND	The employees can complete their tasks on their own way	3
		12j	AND	The company facilitates the employees for knowledge sharing	3
		12k	AND	The company is open-up for advice and feedback from the employees	3
			THEN	The company had a good leadership and corporate culture to achieve Employee Engagement.	
			OR	The company had to reform the leadership and corporate culture to achieve Employee Engagement.	
13	**Which tools does the company use to measure its Employee Engagement?**				
Empl Engagement Control		13a	AND	The achievement of Employee Engagement programmes is measured through Employee Satisfaction Survey	2
		13b	AND	The achievement of Employee Engagement programmes is measured through Employee Retention	2
		13c	AND	The achievement of Employee Engagement programmes is measured through Employee Productivity	2
			THEN	The company has measured Employee Engagement achievement and can identify Employee Engagement level.	
			OR	The company has not measured Employee Engagement achievement properly.	

Social & Envr Issue	**social**	**16**	IF	The company considers that social welfare initiatives are important for both the company existence and the community empowerment	9
Sustainability	management commitment	17a	AND	The company has social programmes	4
		17b	AND	The company allocates specific budget for social programmes	5
		17c	AND	The social programmes are communicated to all company members	5
		17d	AND	The social programmes are reviewed regularly	5
		17e	AND	The social programmes involves local community	7
18	**Which social programmes has the company taken action on?**				
	programmes	18a	AND	# Educational programme(s)	5
		18b	AND	# Public health	5
		18c	AND	# Human right	5
		18d	AND	# Safety	5
			THEN	The company had a strong commitment in social welfare initiative.	
			OR	The company has not fully committed to social welfare initiative.	
	environmental	**19**	IF	The company considers that sustainable environmental programmes are important for both the company existence and the community empowerment	9
	management commitment	20a	AND	The company has environmental programmes	4
		20b	AND	The company allocates specific budget for environmental programmes	5
		20c	AND	The environmental programmes are communicated to all company members	5
		20d	AND	The environmental programmes are reviewed regularly	5
		20e	AND	The environmental programmes involves local community	7
21	**Which environmental programmes has the company taken action on?**				
	programmes	21a	AND	# Waste and pollution reduction process	5
		21b	AND	# Energy saving	5
		21c	AND	# Renewable energy	5
			THEN	The company had a strong commitment in sustainable environmental programmes.	
			OR	The company has not fully committed to sustainable environmental programmes.	

(*)	"Always (>95%)"	GP
	"Frequently (75-95%)"	PC-5
	"Sometimes (50 - 75%)"	PC-4
	"Occasionally (25 - 50%)"	PC-3
	"Rarely (< 25%)"	PC-2

2.1 Module: Manufacturing Perspective, Sub Module: Body Part Manufacturing Equipment

Dimension	KPI	KB Rule			GAP (PC)
Mfg Equipment - Organisational Support	policy	1	IF	Does your company consider the importance of policies or formal documents on Body Part Manufacturing equipment?	9
2	**Please confirm the roles of Top Level Management related to policies and programmes on Body Parts manufacturing equipment :**				
	TLM/MLM	2a	AND	Creating policies	1
		2b	AND	Assisting Middle Level Management in developing plans and programmes related to policies	1
		2c	AND	Approving plans/programmes related to policies	1
		2d	AND	Reviewing policies	1
		2e	AND	Reviewing programmes	1
		2f	AND	Communicating all policies to the lower management levels	1
		2g	AND	Assisting the implementation of policies and programmes on the lower management levels	1
		2h	AND	Connecting relevant functions to execute programmes	2
		2i	AND	Allocating specific budget to support plans and programmes	2
		2j	AND	Determining KPIs to measure performance	3
		2k	AND	Determining key benchmarks	3
		2l	AND	Determining performance targets	3
3		3	AND	Does the Middle Level Management actively contribute to the development of plans and programmes related to policies of manufacturing equipment on Body Part Manufacturing?	1
if yes, then	**Please confirm the roles of Middle Level Management related to policies and programmes on Body Parts manufacturing equipment :**				
	TLM/MLM	3a	AND	Creating plans and programmes related to policies	1
		3b	AND	Communicating with Top Level Management in translating policy into programmes	1
		3c	AND	Assisting Lower Level Management in developing systems and procedures	1
		3d	AND	Approving systems and procedures related to programmes	1
		3e	AND	Reviewing plans and programmes	1
		3f	AND	Reviewing systems and procedures	1
		3g	AND	Communicating all policies and programmes to lower management level	1
		3h	AND	Assisting the implementation of policies and programmes on lower management level	1
		3i	AND	Connecting relevant functions to execute programmes	2

		3j	AND	Being involved in determining specific budget to support plans and programmes	2
		3k	AND	Being involved in determining KPIs to measure performance	3
		3l	AND	Being involved in determining key benchmarks	3
		3m	AND	Being involved in determining performance targets	3
		3n	AND	Proposing future plans, programmes and budgets	3
4		4	AND	Does the Lower Level Management actively contribute to the implementation of manufacturing equipment policies and programmes on Body Part Manufacturing?	1
if yes, then	Please confirm the roles of Lower Level Management related to policies and programmes on Body Parts manufacturing equipment :				
	LLM	4a	AND	Developing system and procedures to execute plans and programmes	1
		4b	AND	Communicating with upper management levels in translating programmes into procedures	1
		4c	AND	Supervising the implementation of plans and programmes	1
		4d	AND	Reviewing plans and programmes	2
		4e	AND	Reviewing system and procedures	2
		4f	AND	Being involved in determining performance indicators (KPIs) for performance measurement	3
		4g	AND	Being involved in determining performance target (expectation)	3
		4h	AND	Being involved in considering benchmark to set the performance target	3
		4i	AND	Reporting performance measurement result	3
		4j	AND	Reviewing performance measurement and providing feedback	3
		4k	AND	Proposing future programmes and procedures	4
			THEN	The company has a strong commitment to support policy of manufacturing equipment on Body Part Manufacturing.	
			OR	The company has not fully committed to support policy of manufacturing equipment on Body Part Manufacturing.	
5	**Which functions are involved on the decision making of Body Parts manufacturing equipment?**				
		5a	AND	Manufacturing function	1
		5b	AND	Research and Development function	1
		5c	AND	Financial function	1
		5d	AND	Maintenance function	1
		5e	AND	Quality function	1
		5f	AND	Procurement function	1
		5g	AND	Third party (supplier for product material)	3
			THEN	Decision of manufacturing equipment has involved relevant cross functional team.	

			OR	Decision of manufacturing equipment has not involved relevant cross functional team.	
Mfg Equipment - Planning	decision criteria	6a	IF	The decision of chosen manufacturing equipment of Body Part Manufacturing is taken based on: # Equipment capacity	1
		6b	AND	# Product requirement and specification	1
		6c	AND	# Health and safety	1
		6d	AND	# Maintainability	2
		6e	AND	# Cost efficiency	3
		6f	AND	# Plant capacity and layout	3
		6g	AND	# Environmental impact analysis	3
		6h	AND	# Sustainable/renewable energy	4
		6i	AND	# Technology change analysis	5
		6j	AND	# Towards world-class manufacturing	6
			THEN	The key aspects has been taken into account for manufacturing equipment decision.	
			OR	Not all key aspects has been taken into account for manufacturing equipment decision.	
Mfg Equipment - Control					
7	**Which information of manufacturing equipment on Body Part Manufacturing below is available:**				
(*)	information	7a	IF	Operation manual	2
(*)		7b	AND	Maintenance manual and technical specification	2
(*)		7c	AND	Installation date	2
(*)		7d	AND	Location	2
(*)		7e	AND	Output of each machine	2
(*)		7f	AND	Maintenance treatment history	2
(*)		7g	AND	Maintenance cost history (labour and material)	2
(*)		7h	AND	Machine disaggregation to parts (cataloguing)	2
(*)		7i	AND	Part criticality	2
(*)		7j	AND	Functional diagnostic checklist	2
(*)		7k	AND	Safety procedures	2
8	**Information obtained about manufacturing equipment is:**				
(*)	information	8a	IF	Available to all those require	2
(*)		8b	AND	Updated regularly	2
(*)		8c	AND	Digitalised	2

(*)		8d	AND	Maintained on a network system	2
			THEN	The information of manufacturing equipment policy has been maintained properly to support manufacturing performance.	
			OR	The information of manufacturing equipment policy has not been maintained properly to support manufacturing performance.	
9	**Based on your record, how do you assess the current performance of manufacturing equipment on Body Part Manufacturing?**				
(*)	capacity & availability	9a	IF	There is sufficient capacity available at a regular cost to fulfil order	2
(*)		9b	AND	Equipment is running based on the manufacturing schedule	2
(*)	reliability	9c	AND	Equipment can produce output within the quality tolerance level	2
(*)	flexibility	9d	AND	Equipment is flexible with dimension variation of product	2
(*)		9e	AND	Equipment is flexible with material variation of product	2
(*)		9f	AND	Equipment has safety features	2
(*)		9g	AND	Equipment has preventive maintenance check up	2
(*)		9h	AND	Percentage of equipment availability	2
(*)		9i	AND	Percentage of equipment reliability	2
(*) (-)		9j	AND	Volume of scrap and rejects due to unreliable equipment	2
(*) (-)		9k	AND	Percentage of machine breakdown	2
			THEN	Manufacturing equipment of Body Part had a good performance based on the designated specification	
			OR	Manufacturing equipment of Body Part had to improve the performance based on the designated specification	

(*)	"Always (>85%)"	GP
	"Frequently (60 - 85%)"	PC-5
	"Sometimes (40 - 60%)"	PC-4
	"Occasionally (25 - 40%)"	PC-3
	"Rarely (< 25%)"	PC-2

(*) (-)	"Rarely (< 25%)"	GP
	"Occasionally (25 - 40%)"	PC-5
	"Sometimes (40 - 60%)"	PC-4
	"Frequently (60 - 85%)"	PC-3
	"Always (>85%)"	PC-2

2.2 Module: Manufacturing Perspective, Sub Module: Body Part Manufacturing Process

Dimension	KPI	KB Rule			GAP (PC)
Mfg Process - Organisational Support	policy	1	IF	Does your company consider the importance of policies or formal documents regarding Body Parts Manufacturing Process?	9
2	**Please confirm the roles of Top Level Management related to policies and programmes on Body Parts Manufacturing Process:**				
	TLM/MLM	2a	AND	Creating policies	1
		2b	AND	Assisting Middle Level Management in developing plans and programmes related to policies	1
		2c	AND	Approving plans/programmes related to policies	1
		2d	AND	Reviewing policies	1
		2e	AND	Reviewing programmes	1
		2f	AND	Communicating all policies to the lower management levels	1
		2g	AND	Assisting the implementation of policies and programmes on lower management levels	1
		2h	AND	Connecting relevant functions to execute programmes	2
		2i	AND	Allocating specific budget to support plans and programmes	2
		2j	AND	Determining KPIs to measure performance	3
		2k	AND	Determining key benchmarks	3
		2l	AND	Determining performance targets	3
3		3	AND	Does the Middle Level Management actively contribute to the development of plans and programmes related to policies of Body Part Manufacturing Process?	1
if yes, then	**Please confirm the roles of Middle Level Management related to policies and programmes on Body Parts Manufacturing Process:**				
	TLM/MLM	3a	AND	Creating plans and programmes related to policies	1
		3b	AND	Communicating with Top Level Management in translating policy into programmes	1
		3c	AND	Assisting Lower Level Management in developing systems and procedures	1
		3d	AND	Approving systems and procedures related to programmes	1
		3e	AND	Reviewing plans and programmes	1
		3f	AND	Reviewing systems and procedures	1
		3g	AND	Communicating all policies and programmes to lower management level	1
		3h	AND	Assisting the implementation of policies and programmes on lower management level	1
		3i	AND	Connecting relevant functions to execute programmes	2

		3j	AND	Being involved in determining specific budget to support plans and programmes	2
		3k	AND	Being involved in determining KPIs to measure performance	3
		3l	AND	Being involved in determining key benchmarks	3
		3m	AND	Being involved in determining performance targets	3
		3n	AND	Proposing future plans, programmes and budgets	3
4		4	AND	Does the Lower Level Management actively contribute to the implementation of policies and programmes on Body Part Manufacturing Process?	1
if yes, then	**Please confirm the roles of Lower Level Management related to policies and programmes on Body Parts Manufacturing Process:**				
4	LLM	4a	AND	Developing system and procedures to execute plans and programmes	1
		4b	AND	Communicating with upper management levels in translating programmes into procedures	1
		4c	AND	Supervising the implementation of plans and programmes	1
		4d	AND	Reviewing plans and programmes	2
		4e	AND	Reviewing system and procedures	2
		4f	AND	Being involved in determining performance indicators (KPIs) for performance measurement	3
		4g	AND	Being involved in determining performance target (expectation)	3
		4h	AND	Being involved in considering benchmark to set the performance target	3
		4i	AND	Reporting performance measurement result	3
		4j	AND	Reviewing performance measurement and providing feedback	3
		4k	AND	Proposing future programmes and procedures	4
			THEN	The company has a strong commitment to support policy of Body Part Manufacturing Process.	
			OR	The company has not fully committed to support policy of Body Part Manufacturing Process.	
5	**Which functions are involved on Body Parts Manufacturing Process?**				
		5a	AND	Manufacturing function	1
		5b	AND	Research and Development function	1
		5c	AND	Maintenance function	1
		5d	AND	Quality function	1
		5e	AND	Procurement function	3
		5f	AND	Marketing function	5
		5g	AND	Third party (supplier)	6
		5h	AND	Third party (customer)	7
			THEN	Decision of Body Part Manufacturing Process has involved relevant cross functional team.	
			OR	Decision of Body Part Manufacturing Process has not involved relevant cross functional team.	

Mfg Process - Planning	Body Parts design	6a	IF	The Body Part designed and developed in: # In-house product design and development team	8
		6b	AND	# Parent (or associate) company	8
		6c	AND	# Third party (outsourcing)	8
7	**Which aspects below are performed in the design and development of Body Part?**				
		7a	IF	Idea generation and product conceptualisation	1
		7b	AND	Business assessment and reviewing product sales forecasts	1
		7c	AND	Concept development	1
		7d	AND	Prototype development	1
		7e	AND	Determine product material requirements	1
		7f	AND	Develop product specification and product performance range	1
		7g	AND	Determine product quality targets	1
		7h	AND	Ease of manufacturing process	2
		7i	AND	Ease of assembly process	2
		7j	AND	Determine dies/tool design	2
		7k	AND	Manufacturing safety	3
			THEN	The company has considered key aspects to support Body Part design process.	
			OR	The company has not fully considered key aspects to support Body Part design process.	
	Dies and Checking Fixtures	8	AND	Does the company has a certain standard in developing suitable dies and checking fixtures to support Body Part machining process?	1
		9a	IF	The dies and checking fixtures are design and developed in: # In-house product design and development team	8
		9b	AND	# Parent (or associate) company	8
		9c	AND	# Third party (outsourcing)	8
10	**Which aspects below are performed in the design and development of dies and checking fixtures for Body Parts?**				
		10a	IF	Minimum process analysis	1
		10b	AND	Design check sheet	1
		10c	AND	Generate press specification	1
		10d	AND	Initial concept check	1
		10e	AND	Design check	1
		10f	AND	Detailing (dimensional) check	1
		10g	AND	Design approval	1
		10h	AND	Design hours monitoring	2

		10i	AND	Design checked by expert	3
		10j	AND	Design approved by expert	3
		10k	AND	Press simulation check	3
			THEN	The company has considered key aspects to develop Body Part dies and checking fixtures.	
			OR	The company has not fully considered key aspects to develop Body Part dies and checking fixtures.	
	Assembly Tools	11	AND	Does the company has a certain standard in developing assembly tools to support Body Part assembly?	1
		12a	IF	The assembly tools are design and developed in: # In-house product design and development team	8
		12b	AND	# Parent (or associate) company	8
		12c	AND	# Third party (outsourcing)	8
13	**Which aspects below are performed in the design and development of assembly tools for Body Part? (tick all that apply)**				
		13a	AND	Assembly jigs drawings are according to the latest Engineering Order	1
		13b	AND	Assembly jigs drawings are based on Assembly Operation Sheet	1
		13c	AND	Assembly jig is designed based on General Dimensions and Tolerance	1
		13d	AND	Assembly jigs drawings are based on General Dimensions and Tolerance	1
		13e	AND	Assembly jigs drawings are according to assembly jigs design standard	2
		13f	AND	Assembly jigs are designed in consideration of cheapest method	3
		13g	AND	Assembly jigs are designed based on the easiest assembly method	3
			THEN	The company has considered key aspects to develop Body Part assembly tools.	
			OR	The company has not fully considered key aspects to develop Body Part assembly tools.	
14	**Which aspects below are considered on deciding the current Body Parts manufacturing process and layout?**				
		14a	IF	Minimising manufacturing cost	2
		14b	AND	Minimising transport/movement time	2
		14c	AND	Minimising inventories	2
		14d	AND	Minimising material waste	2
		14e	AND	Maximising flexibility	2
		14f	AND	Maximising product quality	3
		14g	AND	Maximising plant utilisation	3
		14h	AND	Minimising overheads	4
		14i	AND	Maximising labour utilisation	4
			THEN	The company has successfully applied effective and efficient Body Parts manufacturing process and layout.	
			OR	The company has not fully applied effective and efficient Body Parts manufacturing process and layout.	
Mfg Process - Control					

15	**In developing Body Parts and the supporting manufacturing tools, which information below is available:**				
(**)	information	15a	IF	Body Parts CAD drawings	2
(**)		15b	AND	Body Parts specifications	2
(**)		15c	AND	Body Parts general dimensions and tolerance	2
(**)		15d	AND	Dies/checking fixtures CAD drawings	2
(**)		15e	AND	Dies/checking fixtures specifications	2
(**)		15f	AND	Dies/checking fixtures general dimensions and tolerance	2
(**)		15g	AND	Assembly tools CAD drawings	2
(**)		15h	AND	Assembly tools specifications	2
(**)		15i	AND	Assembly tools general dimensions and tolerance	2
(**)		15j	AND	Pressing process planning	2
(**)		15k	AND	Pressing process procedures	2
(**)		15l	AND	Welding process planning	2
(**)		15m	AND	Welding process procedures	2
(**)		15n	AND	Painting process planning	2
(**)		15o	AND	Painting process procedures	2
(**)		15p	AND	Assembly process planning	2
(**)		15q	AND	Assembly process procedures	2
(**)		15r	AND	Safety check sheets	2
(**)		15s	AND	Quality inspection check sheet	2
16	**Information obtained about Body Parts manufacturing process is:**				
(**)	information	16a	AND	Available to all those require	2
(**)		16b	AND	Updated regularly	2
(**)		16c	AND	Digitalised (electronic copy)	2
(**)		16d	AND	Maintained on a network system	2
			THEN	The information of Body Part design process policy has been maintained properly to support manufacturing performance.	
			OR	The information of Body Part design process policy has not been maintained properly to support manufacturing performance.	
17	**Based on your record, how do you assess the current performance of Body Part Manufacturing process in term of:**				
(*)		17a	IF	On-time delivery	2
(*)		17b	AND	Manufacturing cycle time	2

(*)		17c	AND	Time to make changeovers	2
(*)(-)		17d	AND	Down time	2
			THEN	The company has measured Body Part Manufacturing process performance properly.	
			OR	The company has not measured Body Part Manufacturing process performance properly.	

(**)	"Always (>85%)"	GP
	"Frequently (60 - 85%)"	PC-5
	"Sometimes (40 - 60%)"	PC-4
	"Occasionally (25 - 40%)"	PC-3
	"Rarely (< 25%)"	PC-2

(*)	"Excellent (>85%)"	GP
	"Good (60 - 85%)"	PC-5
	"Fair (40 - 60%)"	PC-4
	"Poor (25 - 40%)"	PC-3
	"Worse (< 25%)"	PC-2

(*) (-)	"Rarely (< 25%)"	GP
	"Occasionally (25 - 40%)"	PC-5
	"Sometimes (40 - 60%)"	PC-4
	"Frequently (60 - 85%)"	PC-3
	"Always (>85%)"	PC-2

2.3 Module: Manufacturing Perspective, Sub Module: Process Quality

Dimension	KPI	KB Rule			GAP (PC)
Mfg Process Quality - Org Support	policy	1	IF	Does your company consider the importance of policies or formal documents regarding Body Parts Manufacturing Process Quality?	9
2	**Please confirm the roles of Top Level Management related to policies and programmes on Body Parts Manufacturing Process Quality:**				
	TLM/MLM	2a	AND	Creating policies	1

		2b	AND	Assisting Middle Level Management in developing plans and programmes related to policies	1
		2c	AND	Approving plans/programmes related to policies	1
		2d	AND	Reviewing policies	1
		2e	AND	Reviewing programmes	1
		2f	AND	Communicating all policies to the lower management levels	1
		2g	AND	Assisting the implementation of policies and programmes on lower management levels	1
		2h	AND	Connecting relevant functions to execute programmes	2
		2i	AND	Allocating specific budget to support plans and programmes	2
		2j	AND	Determining KPIs to measure performance	3
		2k	AND	Determining key benchmarks	3
		2l	AND	Determining performance targets	3
3		3	AND	Does the Middle Level Management actively contribute to the development of plans and programmes related to policies of Body Part Manufacturing Process Quality?	1
if yes, then	**Please confirm the roles of Middle Level Management related to policies and programmes on Body Parts Manufacturing Process Quality:**				
	TLM/MLM	3a	AND	Creating plans and programmes related to policies	1
		3b	AND	Communicating with Top Level Management in translating policy into programmes	1
		3c	AND	Assisting Lower Level Management in developing systems and procedures	1
		3d	AND	Approving systems and procedures related to programmes	1
		3e	AND	Reviewing plans and programmes	1
		3f	AND	Reviewing systems and procedures	1
		3g	AND	Communicating all policies and programmes to lower management level	1
		3h	AND	Assisting the implementation of policies and programmes on lower management level	1
		3i	AND	Connecting relevant functions to execute programmes	2
		3j	AND	Being involved in determining specific budget to support plans and programmes	2
		3k	AND	Being involved in determining KPIs to measure performance	3
		3l	AND	Being involved in determining key benchmarks	3
		3m	AND	Being involved in determining performance targets	3
		3n	AND	Proposing future plans, programmes and budgets	3
4		4	AND	Does the Lower Level Management actively contribute to the implementation of policies and programmes on Body Part Manufacturing Process Quality?	1
if yes, then	**Please confirm the roles of Lower Level Management related to policies and programmes on Body Parts Manufacturing Process Quality:**				
	LLM	4a	AND	Developing system and procedures to execute plans and programmes	1

		4b	AND	Communicating with upper management levels in translating programmes into procedures	1
		4c	AND	Supervising the implementation of plans and programmes	1
		4d	AND	Reviewing plans and programmes	1
		4e	AND	Reviewing system and procedures	1
		4f	AND	Being involved in determining performance indicators (KPIs) for performance measurement	3
		4g	AND	Being involved in determining performance target (expectation)	3
		4h	AND	Being involved in considering benchmark to set the performance target	3
		4i	AND	Reporting performance measurement result	3
		4j	AND	Reviewing performance measurement and providing feedback	3
		4k	AND	Proposing future programmes and procedures	4
			THEN	The company has a strong commitment to support policy of Body Part Manufacturing Process Quality.	
			OR	The company has not fully committed to support policy of Body Part Manufacturing Process Quality.	
5	**Which functions are involved on Body Part Manufacturing Process Quality?**				
		5a	AND	Quality function	1
		5b	AND	Manufacturing function	1
		5c	AND	Research and Development function	1
		5d	AND	Maintenance function	1
		5e	AND	Procurement function	3
		5f	AND	Marketing function	3
		5g	AND	Third party (supplier)	4
		5h	AND	Third party (customer)	5
			THEN	Decision of Body Part Manufacturing Process Quality has involved relevant cross functional team.	
			OR	Decision of Body Part Manufacturing Process Quality has not involved relevant cross functional team.	
Quality Planning		6	IF	Does your company apply Total Quality Management (TQM) approach?	2
if yes, then	**Which stakeholders are involved in TQM implementation?**				
6		6a	AND	Employees	2
		6b	AND	Suppliers	3
		6c	AND	Distributors	4
		6d	AND	Customers	6
7	**Which aspect that you emphasise in developing relationship with suppliers for Body Parts manufacturing process quality?**				
		7a	AND	Incoming Material Quality	2
		7b	AND	On-Time supply	2

8	**Which quality improvement approaches below are applied in Body Parts manufacturing process quality?**				
		8a	AND	Quality is built in (prevention) on each process, not inspection or detection at final stage	2
		8b	AND	Management led to quality	2
		8c	AND	Everyone is responsible for quality	2
		8d	AND	Right since the first time	2
		8e	AND	Applied on entire organisation activities	2
		8f	AND	Continuous improvement	2
9	**Which tools and techniques below are used by the company to ensure process quality?**				
		9a	AND	Check sheets	5
		9b	AND	Histograms	5
		9c	AND	Quality Function Deployment	5
		9d	AND	Pareto charts	5
		9e	AND	Fishbone (cause and effect) diagrams	5
		9f	AND	Statistical Process Control (SPC) charts	5
		9g	AND	Scatter diagrams	5
		9h	AND	Other	5
10	**In improving Body Parts manufacturing process quality, which information below is available:**				
Process Quality - Control					
(**)		10a	IF	Conformance to specification rate	2
(**)		10b	AND	Product reject rate	2
(**)		10c	AND	Scrap	2
(**)		10d	AND	Rework	2
(**)		10e	AND	Material waste	2
11	**Information obtained about Body Parts manufacturing process quality is:**				
(**)	information	11a	AND	Available to all cross functional team who require	2
(**)		11b	AND	Updated regularly	2
(**)		11c	AND	Digitalised (electronic copy)	2
(**)		11d	AND	Maintained on a network system	2
			THEN	The information of Body Part design process policy has been maintained properly to support manufacturing performance.	

			OR	The information of Body Part design process policy has not been maintained properly to support manufacturing performance.	
12	**Based on your record, how do you assess the current performance of Body Part Manufacturing Process Quality in term of:**				
(*)		12a	IF	Yield	2
(*)		12b	AND	Supplier's Quality Incoming	2
(*)(-)		12c	AND	Rejects/Return Material	2
			THEN	The company has measured Body Part Manufacturing process quality performance properly.	
			OR	The company has not measured Body Part Manufacturing process quality performance properly.	

(**)	"Always (>85%)"	GP
	"Frequently (60 - 85%)"	PC-5
	"Sometimes (40 - 60%)"	PC-4
	"Occasionally (25 - 40%)"	PC-3
	"Rarely (< 25%)"	PC-2

(*)	"Excellent (>85%)"	GP
	"Good (60 - 85%)"	PC-5
	"Fair (40 - 60%)"	PC-4
	"Poor (25 - 40%)"	PC-3
	"Unacceptable (< 25%)"	PC-2

(*) (-)	"Rarely (< 25%)"	GP
	"Occasionally (25 - 40%)"	PC-5
	"Sometimes (40 - 60%)"	PC-4
	"Frequently (60 - 85%)"	PC-3
	"Always (>85%)"	PC-2

3.1 Module: Maintenance Rules, Sub Module: Policy

Dimension	KPI	KB Rule			GAP (PC)
Management - TLM/MLM	policy	1	IF	Does your company consider the importance of policies or formal documents regarding maintenance of Body Part Manufacturing Equipment?	9

2	**Please confirm the roles of Top Level Management related to policies and programmes on maintenance of Body Parts Manufacturing Equipment :**				
	TLM	2a	AND	Creating policies	1
		2b	AND	Assisting Middle Level Management in developing plans and programmes related to policies	1
		2c	AND	Approving plans/programmes related to policies	1
		2d	AND	Reviewing policies	1
		2e	AND	Reviewing programmes	1
		2f	AND	Communicating all policies to the lower management levels	1
		2g	AND	Assisting the implementation of policies and programmes on lower management levels	1
		2h	AND	Connecting relevant functions to execute programmes	2
		2i	AND	Allocating specific budget to support plans and programmes	2
		2j	AND	Determining KPIs to measure performance	3
		2k	AND	Determining key benchmarks	3
		2l	AND	Determining performance targets	3
3		3	AND	Does the Middle Level Management actively contribute to the development of plans and programmes related to maintenance policies on Body Part Manufacturing Equipment?	1
if yes, then	Please confirm the roles of Middle Level Management related to policies and programmes on maintenance of Body Parts Manufacturing Equipment :				
	MLM	3a	AND	Creating plans and programmes related to policies	1
		3b	AND	Communicating with Top Level Management in translating policy into programmes	1
		3c	AND	Assisting Lower Level Management in developing systems and procedures	1
		3d	AND	Approving systems and procedures related to programmes	1
		3e	AND	Reviewing plans and programmes	1
		3f	AND	Reviewing systems and procedures	1
		3g	AND	Communicating all policies and programmes to lower management level	1
		3h	AND	Assisting the implementation of policies and programmes on lower management level	1
		3i	AND	Connecting relevant functions to execute programmes	2
		3j	AND	Being involved in determining specific budget to support plans and programmes	2
		3k	AND	Being involved in determining KPIs to measure performance	3
		3l	AND	Being involved in determining key benchmarks	3
		3m	AND	Being involved in determining performance targets	3
		3n	AND	Proposing future plans, programmes and budgets	3
4		4	AND	Does the Lower Level Management actively contribute to the implementation of maintenance policies and programmes on Body Part Manufacturing Equipment?	1

if yes, then	Please confirm the roles of Lower Level Management related to policies and programmes on maintenance of Body Parts Manufacturing Equipment:				
	LLM	4a	AND	Developing system and procedures to execute plans and programmes	1
		4b	AND	Communicating with upper management levels in translating programmes into procedures	1
		4c	AND	Supervising the implementation of plans and programmes	1
		4d	AND	Reviewing plans and programmes	1
		4e	AND	Reviewing system and procedures	1
		4f	AND	Being involved in determining performance indicators (KPIs) for performance measurement	3
		4g	AND	Being involved in determining performance target (expectation)	3
		4h	AND	Being involved in considering benchmark to set the performance target	3
		4i	AND	Reporting performance measurement result	3
		4j	AND	Reviewing performance measurement and providing feedback	3
		4k	AND	Socialising maintenance initiatives to the organisation	3
		4l	AND	Proposing future programmes and procedures	4
5	**Does the maintenance department of Body Parts Manufacturing Equipment has formal and written procedures in term of:**				
	procedures	5a	AND	Coordinating maintenance work demand with resources	2
		5b	AND	Scheduling maintenance resources to fulfil maintenance work	2
		5c	AND	Dispatching maintenance work	2
		5d	AND	Executing maintenance work	2
6	**Which functions are involved on maintenance of Body Parts Manufacturing Equipment?**				
		6a	AND	Manufacturing function	1
		6b	AND	Quality function	2
		6c	AND	Research and Development function	2
		6d	AND	Financial function	3
		6e	AND	Procurement function	3
		6f	AND	Marketing function	6
		6g	AND	Third party (supplier)	7
Control					
7	**Has the company been implementing the maintenance strategies below?**				
	general	7a	AND	Time or Run-Based Maintenance	8
		7b	AND	Condition-Based/Preventive Maintenance	8
		7c	AND	Opportunity Maintenance	8
		7d	AND	Fault Finding	8

		7e	AND	Design Modification	8
		7f	AND	Overhaul	8
		7g	AND	Replacement	8
8	**Which method do you use to assess whether the initial maintenance performance has been met or not in a regular basis?**				
	benchmark	8a	AND	Competitor benchmarking	3
		8b	AND	Industry benchmarking	3
		8c	AND	Best-in-class benchmarking	3
		8d	AND	Compare to the best previous performance	4
		8e	AND	Compare to the technical standard	4
		8f	AND	Compare to other departments or plants in the company	4
		8g	AND	Compare to average performance in the certain period	4
		8h	AND	Compare to the last period performance	4
9	**Please respond to the statements below related to evaluation on maintenance performance on Body Part Manufacturing:**				
	Evaluation	9a	AND	The company reviews maintenance performance regularly	2
		9b	AND	The company takes the feedback from relevant staff regarding maintenance performance	2
		9c	AND	The evaluation result is communicated through the maintenance department	3
		9d	AND	The evaluation result is communicated through the organisation	5
			THEN	The company has a strong commitment to support maintenance of Body Part manufacturing equipment.	
			OR	The company has not fully committed to support maintenance of Body Part manufacturing equipment.	
10	**How do you rate your company's commitment on maintenance regarding the matrices below:**				
(*)	financial	10a	AND	Maintenance budget	2
(*)		10b	AND	Maintenance budget / total net sales	2
(*)		10c	AND	Cost of outsourcing maintenance / total maintenance operational costs	2
(*)	coordination	10d	AND	The coordination between supervisors and technicians to fulfil maintenance work order	2
(*)		10e	AND	The coordination between manufacturing operators with maintenance personnel	2
(*)		10f	AND	Clear job description and role of manufacturing and maintenance personnel toward manufacturing equipment	2
(*)	hse & quality	10g	AND	Management commitment on healthy issue	2
(*)		10h	AND	Management commitment on safety issue	2
(*)		10i	AND	Management commitment on environment issue	2
(*)		10j	AND	Management commitment on quality issue	2

(*)	"Excellent (>85%)"	GP
	"Good (60 - 85%)"	PC-5
	"Fair (40 - 60%)"	PC-4
	"Poor (25 - 40%)"	PC-3
	"Worse (< 25%)"	PC-2

3.2 Module: Maintenance Rules, Sub Module: Organisation

Dimension	KPI	KB Rule			GAP (PC)
Maintenance Org - Planning					
1	**Does your company has a clear organisation structure (in term of centralisation, decentralisation, mixed) on:**				
		1a	IF	Maintenance personnel	9
		1b	AND	Maintenance tools and equipment	9
		1c	AND	Maintenance inventories (spare parts)	9
		1d	AND	Computerised Maintenance Management System (CMMS)	9
2	**Which aspects below are considered to decide the type of maintenance organisation in Body Part Manufacturing (centralisation, decentralisation, or mixed):**				
		2a	AND	Maintenance load	3
		2b	AND	Size of plant	3
		2c	AND	Maintenance personnel skill	3
		2d	AND	Machine specialisation	3
		2e	AND	Maintenance task complexity	3
		2f	AND	Organisation structure	5
		2g	AND	Organisation culture	7
	Outsourcing	3	AND	Have the maintenance works ever been delegated to third party (outsourcing)?	9
3	**Which criteria below have been considered to delegate maintenance works to third party (outsourcing)?**				
		3a	AND	In-house maintenance capacity is not sufficient to carry out expected maintenance tasks	2
		3b	AND	Expected volume of maintenance tasks is too small and the variety of maintenance-related specialist skills is too wide to provide in-house maintenance personnel	4
		3c	AND	Work for which the skill of specialists is required on a routine basis and which is readily available in the market on a competitive basis	4
		3d	AND	Outsourcing is cheaper than recruiting in-house maintenance personnel	4

		3e	AND	Agreement with equipment manufacturer	6
			THEN	The company has considered relevant reasons to take outsourcing decision	
			OR	The company need to review its outsourcing decision based on relevant reasons	
Maintenance Org - Control					
4	**Based on your record, how do you assess the current state of your maintenance organisation in term of:**				
(*)		4a	AND	Flexibility of maintenance job allocation	2
(*)		4b	AND	Flexibility of assigning work load to maintenance personnel	2
(*)		4c	AND	Availability of maintenance personnel	2
(*)		4d	AND	Duration to complete maintenance job	2
(*)		4e	AND	Clear authority with minimum overlap	2
(*)		4f	AND	Supervision of maintenance tasks	2
(*)		4g	AND	Supervision of maintenance inventories (spare parts)	2
(*)		4h	AND	Outsourcing of maintenance work related to business strategy	2
(*)		4i	AND	Relationship with outsourcing suppliers	2
(*)		4j	AND	Efficiency of transportation cost of maintenance	2
(*)		4k	AND	Effective maintenance reporting	2
			THEN	The company has a strong commitment to manage maintenance organisation of Body Part manufacturing equipment.	
			OR	The company has not fully committed to manage maintenance organisation of Body Part manufacturing equipment.	

(*)	"Excellent (>85%)"	GP
	"Good (60 - 85%)"	PC-5
	"Fair (40 - 60%)"	PC-4
	"Poor (25 - 40%)"	PC-3
	"Worse (< 25%)"	PC-2

3.3 Module: Maintenance Rules, Sub Module: Information & Documentation

Dimension	KPI	KB Rule			GAP (PC)
Information & Documentation - Planning					
1	**Which information below is available in maintenance information system?**				
		1a	IF	Inventory number, unit description, and site	1
		1b	AND	Person or department requesting the work	1
		1c	AND	Work description and standard time to complete the task	1
		1d	AND	Job specification	1
		1e	AND	Work priority and work due date	1
		1f	AND	Spare parts required	1
		1g	AND	Tools required	1
		1h	AND	Maintenance work procedures	1
		1i	AND	Maintenance resources availability	1
		1j	AND	Maintenance resources allocation	2
		1k	AND	Backlog	2
		1l	AND	Technical information (drawings and manuals)	2
2	**Which information below is used to support maintenance control?**				
		2a	AND	Actual time taken to complete maintenance task	2
		2b	AND	Mean time to failure (MTTF) for each machine	2
		2c	AND	Mean time to repair (MTTR) for each machine	2
		2d	AND	Mean time between failure (MTBF) for each machine	2
		2e	AND	Mean time between repairs (MTBR) for each machine	2
		2f	AND	Mean time to first failure for each machine	2
		2g	AND	Performance and quality standards	2
		2h	AND	Cause and consequences of failure	2
Information & Documentation - Control					

3	**Based on your record, how do you assess the current state of your maintenance information and documentation in term of:**				
(*)	information	3a	IF	Updated regularly	2
(*)		3b	AND	Accessible to those who require it to complete their task	2
(*)		3c	AND	Can be modified by authorised people only	2
(*)		3d	AND	Has tracking tools to identify any change and people who made the changes	2
(*)		3e	AND	Synchronised in digital version for ease of use	2
(*)		3f	AND	Maintained on a network system	2
(*)		3g	AND	Integrated with organisational performance management information system	2
			THEN	The information of manufacturing equipment policy has been maintained properly to support manufacturing performance.	
			OR	The information of manufacturing equipment policy has not been maintained properly to support manufacturing performance.	

(*)	"Always (>85%)"	GP
	"Frequently (60 - 85%)"	PC-5
	"Sometimes (40 - 60%)"	PC-4
	"Occasionally (25 - 40%)"	PC-3
	"Rarely (< 25%)"	PC-2

4.1 Module: Maintenance Activities, Sub Module: Repair

Dimension	KPI	KB Rule			GAP (PC)
Repair - Planning					
1	**How the Repair Activity on maintenance department is considered on your company?**				
(-)		1a	IF	As minor maintenance activity (<20%)	2
		1b	AND	As emergency maintenance	3
		1c	AND	As part of preventive maintenance	3
2	**To perform Repair Activity, does the company has 'priority classification' related to:**				
		2a	AND	The risk of failure	2
		2b	AND	The cost of failure	2

3	**Does the company have formal procedures to minimise time on corrective maintenance steps below?**				
		3a	AND	Localisation the failure within the system to a specific item/equipment	3
		3b	AND	Recognition the existence of a failure	3
		3c	AND	Diagnosing within the item/equipment to identify specific failed part/component	3
		3d	AND	Replacing or repairing failed item/part/component	3
		3e	AND	Checking out and returning the system to service	3
Repair - Control					
4	**Please confirm the conditions below related to Repair Activity under Preventive Maintenance policies (tick all that apply):**				
(***)		4a	AND	The deterioration of equipment has been detected earlier	2
(***)		4b	AND	The equipment is repaired after its expected life time	2
(***)		4c	AND	The equipment is repaired just before the functional failure	2
(***)		4d	AND	The equipment is repaired due to run-to-failure approach	2
(***)		4e	AND	The action of repairing is part of planned maintenance schedule	2
(***)		4f	AND	The action of repairing is done by the planned maintenance resources	2
(***)		4g	AND	The action of repairing is preferable than replacement	2
5	**Based on your record, how do you rate the current performance of Repair Activity on Body Part manufacturing in term of:**				
(*)		5a	AND	Utilisation rate for each machine	2
(*) (-)		5b	AND	Percentage of maintenance work completed through overtime	2
(**) (-)		5c	AND	Repair cost for each machine compared to overall maintenance cost	2
(**) (-)		5d	AND	Mean time between failure	2
(**) (-)		5e	AND	Mean time to repair	2
(**) (-)		5f	AND	Failure rate	2
			THEN	The Repair Activity is performed under normal Preventive Maintenance circumstances.	
			OR	The Repair Activity is not performed under normal Preventive Maintenance circumstances.	

(***)	"Always (>85%)"	GP
	"Frequently (60 - 85%)"	PC-5
	"Sometimes (40 - 60%)"	PC-4
	"Occasionally (25 - 40%)"	PC-3
	"Rarely (< 25%)"	PC-2

(*)	"Excellent (>85%)"	GP
	"Good (60 - 85%)"	PC-5
	"Fair (40 - 60%)"	PC-4
	"Poor (25 - 40%)"	PC-3
	"Worse (< 25%)"	PC-2

(*) (-)	"< 25%"	GP
	"25 - 40%"	PC-5
	"40 - 60%"	PC-4
	"60 - 85%"	PC-3
	">85%"	PC-2

(**) (-)	"Low (< 25%)"	GP
	"Somewhat low (25 - 40%)"	PC-5
	"Moderate (40 - 60%)"	PC-4
	"Somewhat high (60 - 85%)"	PC-3
	"High (>85%)"	PC-2

4.2 Module: Maintenance Activities, Sub Module: Retain

Dimension	**KPI**	**KB Rule**			**GAP (PC)**
Retain - Planning		1	IF	Does your company consider that maintaining equipment on its designed performance and avoiding failure (Retain Activity) as your main maintenance policy?	2
2	**Which basic maintenance tasks below are performed by operator of manufacturing equipment?**				
		2a	IF	Inspection	3
		2b	AND	Servicing	3
		2c	AND	Calibration	3
		2d	AND	Testing	3
		2e	AND	Alignment	3
		2f	AND	Adjustment	3
		2g	AND	Installation	3
	predictive	3	AND	Does the company implement Predictive Maintenance/Condition-Based Approach?	2

	if yes,	4	AND	Does the company implement Root Cause Analysis on Predictive Maintenance/ Condition-Based Maintenance?	3
4	**Does your company has formal procedures below to implement each step of Root Cause Analysis?**				
	if yes	4a	AND	Defining the problem	3
		4b	AND	Gathering data and evidence	3
		4c	AND	Finding the cause of problem and the causal relationships associated with it	3
		4d	AND	Identifying the way to remove the causes or to prevent recurrence of the problem	3
		4e	AND	Establishing whether solutions that prevent recurrence are within control	3
		4f	AND	Meet objectives and do not cause other problems	3
		4g	AND	Implementation of the proposed solutions	3
		4h	AND	Monitoring of these solutions to assess their effectiveness	3
5	**Which aspects does your company consider to establish maintenance assignment frequency of equipment?**				
		5a	AND	Energy consumption	3
		5b	AND	Machine age	3
		5c	AND	Failure rate	3
		5d	AND	Percentage of reliability	3
		5e	AND	Percentage of machine downtime	3
		5f	AND	Machine speed loss rate	3
		5g	AND	Percentage of availability	3
Retain - Control					
6	**Please confirm the conditions below to see the Retain Activity is under normal Preventive Maintenance (PM) practice:**				
(*)		6a	AND	Scheduled Retain Activity (Preventive and Predictive Maintenance)	2
(**)		6b	AND	Downtime trend is recorded and reported regularly	2
(**)		6c	AND	Check sheets are controlled to assure 100% compliance	2
(**)		6d	AND	Lubricant routes are scheduled and performed on time-basis	2
(**)		6e	AND	Data processing is used to scheduled and report Preventive Maintenance inspection and lubrication	2
(**)		6f	AND	Foreseeable problems which are discovered through PM inspection is reported as soon as possible	2
(**)		6g	AND	Analysis of breakdown reports is performed to detect failure pattern and propose PM program	2
7	**Based on your record, how do you rate the current performance of Retain Activity on Body Part manufacturing in term of:**				
(*)		7a	AND	Availability of maintenance resources to execute maintenance planning	2
(***)		7b	AND	Response time of the maintenance team	2
(***)		7c	AND	Overall Equipment Effectiveness (OEE)	2
(***)(-)		7d	AND	Time required to repair machine as expected	2

(***)(-)		7e	AND	Backlog of maintenance work	2
(***)(-)		7f	AND	Percentage of maintenance work completed through overtime	2
			THEN	The Retain Activity is performed under normal Preventive Maintenance circumstances.	
			OR	The Retain Activity is not performed under normal Preventive Maintenance circumstances.	

(*)	">85%"	GP
	"60 - 85%"	PC-5
	"40 - 60%"	PC-4
	"25 - 40%"	PC-3
	"< 25%"	PC-2

(**)	"Always (>85%)"	GP
	"Frequently (60 - 85%)"	PC-5
	"Sometimes (40 - 60%)"	PC-4
	"Occasionally (25 - 40%)"	PC-3
	"Rarely (< 25%)"	PC-2

(***)	"Excellent (>85%)"	GP
	"Good (60 - 85%)"	PC-5
	"Fair (40 - 60%)"	PC-4
	"Poor (25 - 40%)"	PC-3
	"Worse (< 25%)"	PC-2

(***) (-)	"Low (< 25%)"	GP
	"Somewhat low (25 - 40%)"	PC-5
	"Moderate (40 - 60%)"	PC-4
	"Somewhat high (60 - 85%)"	PC-3
	"High (>85%)"	PC-2

4.3 Module: Maintenance Activities, Sub Module: Modification

Dimension	KPI	KB Rule			GAP (PC)
Modification - Planning		1	IF	Does your company consider that Modification of Equipment is part of your maintenance activities?	3
2	**On which aspects below Modification Activity is performed in your maintenance department?**				
		2a	AND	Equipment design	5
		2b	AND	Workmanship	5
		2c	AND	Equipment installation	5
		2d	AND	Maintenance scheduling	5
		2e	AND	Maintenance procedures	5
	TPM/OEE	3	AND	Do you implement Total Productive Maintenance (TPM) on Modification Activity?	3
4	**Please confirm the statement below regarding TPM implementation on Modification Activity:**				
		4a	AND	Participation of related employees from top management to operators	3
		4b	AND	Improving maintenance skill towards adopted manufacturing technology and to tackle maintenance issues	3
		4c	AND	Developing cross-functional team to promote ideas	3
		4d	AND	Integrating data of preventive maintenance and predictive maintenance activities as source for TMP implementation on Modification	3
Modification - Control					
5	**Based on your record, how do you rate the maintenance performance on Modification Activity in term of:**				
(*)		5a	AND	Reducing downtime	2
(*)		5b	AND	Improving equipment effectiveness	2
(*)		5c	AND	Improving productivity	2
(*)		5d	AND	Improving workplace safety and environment issues	2
(*)		5e	AND	Eliminating production losses	2
		5f	AND	Maximising Overall Equipment Effectiveness (OEE)	2
			THEN	The Modification Activity is performed well and supported by the organisation.	
			OR	The Modification Activity is not performed well and is not fully supported by the organisation.	

(*)	"Excellent (>85%)"	GP
	"Good (60 - 85%)"	PC-5
	"Fair (40 - 60%)"	PC-4
	"Poor (25 - 40%)"	PC-3
	"Worse (< 25%)"	PC-2

4.4 Module: Maintenance Activities, Sub Module: Design

Dimension	KPI	KB Rule			GAP (PC)
Design - Planning		1	IF	Does your company consider that Design of Equipment is part of your maintenance activities?	3
2	**On which aspects below Design Activity are performed in your maintenance department?**				
		2a	AND	Equipment design	5
		2b	AND	Workmanship	5
		2c	AND	Equipment installation	5
		2d	AND	Maintenance scheduling	5
		2e	AND	Maintenance procedures	5
	TPM/OEE	3	AND	Do you implement Total Productive Maintenance (TPM) on Body Part manufacturing equipment?	3
4	**Please confirm the statement below regarding TPM implementation in your company:**				
		4a	AND	Participation from all employees from top management to operators to implement TPM	3
		4b	AND	Improving maintenance skill towards adopted manufacturing technology and to tacke maintenance issues	3
		4c	AND	Developing cross-functional team to promote ideas for Design Activity	3
		4d	AND	Integrating preventive maintenance and predictive maintenance activities as source for TMP implementation	3
Design - Control					
5	**Based on your record, how do you rate the maintenance performance when performing Design Activity in term of:**				
(*)		5a	AND	Reducing downtime	2
(*)		5b	AND	Improving equipment effectiveness	2
(*)		5c	AND	Improving productivity	2
(*)		5d	AND	Improving workplace safety and environment issues	2
(*)		5e	AND	Eliminating production losses	2
		5f	AND	Maximising Overall Equipment Effectiveness (OEE)	2
			THEN	The Design Activity is performed well and supported by the organisation.	
			OR	The Design Activity is not performed well and is not fully supported by the organisation.	

(*)	"Excellent (>85%)"	GP
	"Good (60 - 85%)"	PC-5
	"Fair (40 - 60%)"	PC-4
	"Poor (25 - 40%)"	PC-3
	"Worse (< 25%)"	PC-2

5.1 Module: Maintenance Resources, Sub Module: Maintenance Personnel

Dimension	KPI	KB Rule			GAP (PC)
1	**Does your company have policies or formal documents regarding maintenance personnel in term of:**				
Maint Personnel - Planning		1a	IF	Skills/competencies	1
		1b	AND	Work load	1
		1c	AND	Team work	3
		1d	AND	Ethic as the company's member	5
	skill/capability/competency of technicians	2	AND	Does your company have skilful maintenance personnel who are responsible to maintain each equipment? (could be one technician for more than one equipment)	2
2	**The skilful personnel technicians are classified based on:**				
		2a	AND	Formal education background	3
		2b	AND	Professional training certification	3
		2c	AND	Internal performance appraisal (based-on experience)	3
3	**Regarding work load of the maintenance technicians for Body Parts manufacturing, does your company take into account:**				
	work load	3a	AND	Number of personnel to handle maintenance planning and scheduling	2
		3b	AND	Number of personnel to configure work flexibility	2
		3c	AND	Shift pattern	2
		3d	AND	Work load safety	2
		3e	AND	Personal expertise	3
		3f	AND	Teamwork capability	3
4	**Does the work load assessment of maintenance personnel integrate with:**				
		4a	AND	Manufacturing planning and schedule	2

		4b	AND	Maintenance schedule for planned maintenance	2
		4c	AND	Emergency maintenance expectation	3
5	**Regarding knowledge sharing and idea sharing of the maintenance personnel of Body Part manufacturing, does the company:**				
		5a	AND	Provide knowledge sharing facilities for the maintenance personnel to socialise and share their knowledge	2
		5b	AND	Provide knowledge sharing facilities for the maintenance and manufacturing personnel to socialise and share their knowledge	2
		5c	AND	Involve maintenance employees in defining work objectives	2
		5d	AND	Accommodate maintenance employees' suggestions to improve maintenance performance?	2
6	**Which methods are used to obtain employees' suggestions?**				
		6a	AND	Brainstorming	5
		6b	AND	Suggestion system	5
		6c	AND	Morning meeting	5
		6d	AND	Integrated in the performance appraisal system	5
Maint Personnel - Control					
7	**Which aspects below have been causing maintenance error on maintenance of Body Part manufacturing equipment, particularly related to maintenance personnel?**				
(-)		7a	AND	Poor work environment	2
(-)		7b	AND	Complex maintenance tasks	2
(-)		7c	AND	Poorly written maintenance procedures	2
(-)		7d	AND	Fatigued maintenance personnel	2
(-)		7e	AND	Inadequate training and experience	2
8	**Based on your record, how do you rate the current performance of maintenance employees on Body Part Manufacturing in term of:**				
(*)		8a	AND	Training hours towards maintenance expertise	2
(*) (-)		8b	AND	Turnover of maintenance employees	2
(*) (-)		8c	AND	Rate of absenteeism	2
(*) (-)		8d	AND	Labour cost of maintenance team compared to maintenance cost	2
(*) (-)		8e	AND	Operation failure after maintenance work due to human error	2
(**)		8f	AND	Maintenance personnel productivity	2
(**)		8g	AND	Maintenance personnel flexibility	2
(**)		8h	AND	Maintenance teamwork performance	2
(**)		8i	AND	Coordination between manufacturing and maintenance personnels	2
(**)		8j	AND	Commitment for continuous training	2

(**)		8k	AND	Incentive schemes	2
			THEN	The company has strong commitment to manage and improve maintenance personnel performance.	
			OR	The company has not strong commitment to manage and improve maintenance personnel performance.	

(*)	"High (>85%)"	GP
	"Somewhat high (60 - 85%)"	PC-5
	"Moderate (40 - 60%)"	PC-4
	"Somewhat low (25 - 40%)"	PC-3
	"Low (< 25%)"	PC-2

(*) (-)	"Low (< 25%)"	GP
	"Somewhat low (25 - 40%)"	PC-5
	"Moderate (40 - 60%)"	PC-4
	"Somewhat high (60 - 85%)"	PC-3
	"High (>85%)"	PC-2

(**)	"Excellent (>85%)"	GP
	"Good (60 - 85%)"	PC-5
	"Fair (40 - 60%)"	PC-4
	"Poor (25 - 40%)"	PC-3
	"Worse (< 25%)"	PC-2

5.2 Module: Maintenance Resources, Sub Module: Tools

Dimension	**KPI**	**KB Rule**			**GAP (PC)**
Tools - Plannning					
1	**Does your maintenance department has classification of maintenance tools in term of:**				
		1a	IF	Tools value (price)	3
		1b	AND	Tools speciality	3
		1c	AND	Tools criticality to downtime or safety	3

2	**Which factors below are considered for maintenance job quality related to maintenance tools?**				
		2a	AND	Regular calibration	2
		2b	AND	Compatibility	2
		2c	AND	Availability	2
		2d	AND	Training	2
Tools - Control					
3	**Which aspects below have ever been causing maintenance error on maintenance of Body Part manufacturing equipment, particularly related to maintenance tools?**				
(-)		3a	AND	Outdated maintenance manual	2
(-)		3b	AND	Poor tools design	2
(-)		3c	AND	Tools malfunction	2
(-)		3d	AND	Poor work layout	2
(-)		3e	AND	Human error in operating tools	2
(-)		3f	AND	Unavailability of special tools	2
(-)		3g	AND	Inaccurate work description	2
(-)		3h	AND	Inaccurate tools information	2
4	**Based on your record, how do you rate the current state of maintenance tools on the maintenance metrics below:**				
(*)(-)		4a	AND	Delay in repair due to lack of maintenance tools	2
(*)(-)		4b	AND	Number of maintenance error due to inaccurate or less presssion tools	2
			THEN	The company has strong commitment to manage maintenance equipment and tools.	
			OR	The company has not strong commitment to manage maintenance equipment and tools.	

(*)(-)	"Low (< 25%)"	GP
	"Somewhat low (25 - 40%)"	PC-5
	"Moderate (40 - 60%)"	PC-4
	"Somewhat high (60 - 85%)"	PC-3
	"High (>85%)"	PC-2

5.3 Module: Maintenance Resources, Sub Module: Material

Dimension	KPI	KB Rule			GAP (PC)
Inventories (Spare Parts) - Planning					
1	**Does your maintenance department has classification of maintenance inventories (spare parts) in term of:**				
		1a	IF	Part value (price)	3
		1b	AND	Part specialisation on particular machines	3
		1c	AND	Part turnover	3
		1d	AND	Part criticality to downtime or safety	3
2	**Does your maintenance department have these procedures to control inventories (spare parts)?**				
		2a	AND	Requisition	3
		2b	AND	Inventory record	3
		2c	AND	Item to be stocked	3
		2d	AND	Order point	3
		2e	AND	Order quantities	3
3	**Which information below is available on each maintenance inventories (spare parts)?**				
		3a	AND	Part specification (type, size, technical information)	2
		3b	AND	Part code (inventory database)	2
		3c	AND	Machine of where the part attached	3
		3d	AND	Site of where the part/machine located	3
		3e	AND	Spare part location in the storeroom	3
		3f	AND	Part manufacturer	3
		3g	AND	Procurement cost	3
		3h	AND	Date acquired or manufactured	3
Inventories (Spare Parts) - Control					
4	**Based on your record, how do you rate the current state of maintenance inventory (spare part) on the maintenance metrics below:**				
(*)(-)		4a	AND	Outdated maintenance inventories (spare parts) cataloguing database	2
(*)(-)		4b	AND	Uncompleted inventory specification information	2
(*)(-)		4c	AND	Wrong inventory codes	2

(*)(-)		4d	AND	Wrong placement of inventories in the storeroom	2
(*)(-)		4e	AND	Double storerooms for placing one type of inventory	2
(*)(-)		4f	AND	Wrong picking up required inventories from the storeroom	2
(*)(-)		4g	AND	Wrong "equipment to parts" decomposition identification and entry to the database	2
(*)(-)		4h	AND	Delay in repair due to lack of spare part	2
			THEN	The company has strong commitment to manage maintenance material (spare parts).	
			OR	The company has not strong commitment to manage maintenance material (spare parts).	

(*) (-)	"Low (< 25%)"	GP
	"Somewhat low (25 - 40%)"	PC-5
	"Moderate (40 - 60%)"	PC-4
	"Somewhat high (60 - 85%)"	PC-3
	"High (>85%)"	PC-2

5.4 Module: Maintenance Resources, Sub Module: ICT

Dimension	KPI	KB Rule			GAP (PC)
ICT - Planning		1	IF	Does your company have an integrated maintenance data and information system?	2
2	**Which maintenance tasks are supported by CMMS?**				
		2a	AND	Data collection	3
		2b	AND	Data processing	3
		2c	AND	Communicating	3
		2d	AND	Maintenance work forecasting	3
		2e	AND	Maintenance planning	3
		2f	AND	Maintenance scheduling	3
		2g	AND	Maintenance reporting	3
		2h	AND	Maintenance controlling	3
ICT - Control					
3	**Which aspects below are the barriers for the maintenance department cannot obtain full benefit of CMMS?**				
(-)		3a	AND	Outdated maintenance record	2
		3b	AND	Unconnected related information/functions	2
		3c	AND	Inadequate training for maintenance planners and engineers in using CMMS	2

		3d	AND	The CMMS does not meet the specific maintenance requirement of the company	2
		3e	AND	The CMMS is not user friendly	2
		3f	AND	The CMMS reports are not considered for maintenance improvement	2
4	**Based on your record, how do you rate the current performance of CMMS on Body Part manufacturing in term of:**				
(*)		4a	AND	Reliability	2
(*)		4b	AND	Accuracy	2
(*)		4c	AND	Security	2
(*)		4d	AND	Ease of use	2
(*)		4e	AND	Quality of information	2
(*)		4f	AND	Timely processing	2
			THEN	The company has strong commitment to manage maintenance ICT.	
			OR	The company has not strong commitment to manage maintenance ICT.	

(*)	"Excellent (>85%)"	GP
	"Good (60 - 85%)"	PC-5
	"Fair (40 - 60%)"	PC-4
	"Poor (25 - 40%)"	PC-3
	"Worse (< 25%)"	PC-2